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OBSERVATIONS OF PORTLAND CEMENT CONCRETE AND POROUS FRICTION COURSE PAVEMENT CONSTRUCTION

by

Frazier Parker, Jr., Robert C. Gunkel, Thomas D. White

Soils and Pavements Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

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The results from inspection trips to five construction sites where portland cement concrete (PCC) pavements were being constructed and one site where a porous friction course was being constructed are reported. The pavements at these sites were being constructed under Corps of Engineers supervision in accordance with job specifications. Construction procedures, job specifications, and inspection and testing procedures were observed to determine if they were compatible with current Corps of Engineers paving
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specifications. Discussions were held with project personnel to obtain their opinions regarding how Corps of Engineers guide specifications (MCGS 02611) and standard practices manual (TM 5-822-7) could be revised to improve compatibility with current construction technology for PCC pavements, and how to develop guide specifications and standard practice procedures for porous friction courses. Recommendations were made based on technical considerations.

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PREFACE

This report was sponsored by the Office, Chief of Engineers, as part of O&MA Project 4K07812AQ61, "Compiled Results from Construction Inspection Trips." The data were collected as part of RDTE Project A4762719AT40, "Construction Design Technology Base."

The investigation was conducted from June 1975 to September 1976 under the supervision of Mr. J. P. Sale, Chief, Soils and Pavements Laboratory (S&PL), U. S. Army Engineer Waterways Experiment Station (WES). Inspection trips were made by Dr. F. Parker, Jr., and Messrs. R. L. Hutchinson, T. D. White, R. C. Gunkel, and G. G. Harvey, all of S&PL. This report was prepared by Dr. Parker and Messrs. Gunkel and White.

Directors of WES during the investigation were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	2.54	centimetres
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
square feet	0.09290304	square metres
square yards	0.8361274	square metres
cubic yards	0.7645549	cubic metres
gallons	0.003785412	cubic metres
pounds (mass)	0.4535924	kilograms
pounds per cubic yard	0.593277	kilograms per cubic metre
kips	4448.222	newtons
pounds per square inch	6894.757	pascals
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15)$.

OBSERVATIONS OF PORTLAND CEMENT CONCRETE AND POROUS FRICTION COURSE PAVEMENT CONSTRUCTION

PART I: INTRODUCTION

Background

1. Pavement construction equipment, techniques, and procedures are constantly changing. New concepts for producing safer, more durable pavements are being developed. Equipment manufacturers are developing new equipment and contractors are experimenting with new procedures to reduce labor requirements and cost. As with anything new, some equipment, construction techniques, and procedures will produce acceptable results while others will not. The Corps of Engineers (CE), or for that matter any specifying agency, must evaluate these innovations and provide guidance for implementation of those which are acceptable to their construction elements.

2. Porous friction surface courses (PFC) have been used in Great Britain as airfield surfaces for a number of years. Their performance has been good both as an antihydroplaning surface and as an all-weather skid-resistant wearing surface. Similarly, PFC or plant-mix seal coats have been used successfully on highways in the United States for several years. It was not until 1971 and 1972 that PFC's were considered for use as airfield pavements. In December 1971, the Federal Aviation Administration (FAA) funded a study conducted by the U. S. Army Engineer Waterways Experiment Station (WES) to develop a mix design procedure and recommended specifications for PFC. In addition, a 3-year evaluation of 10 PFC pavements was conducted. The 10 pavements comprised both commercial and military facilities. The results of this study are reported in References 1 and 2.

3. Except for test applications at WES, the first application of the recommended PFC mix design procedures and specifications by the CE was undertaken by the Missouri River Division (MRD). This PFC pavement

was placed at Scott AFB in May 1976. The construction site was visited during the laydown operation by WES personnel.

4. The CE has guide specifications (MCGS 02611)[3] and a standard practices manual (TM 5-822-7)[4] to provide guidance to the various CE districts and divisions for preparing job specifications and inspecting and controlling the construction of portland cement concrete (PCC) pavements. As construction equipment, techniques, and procedures change, these documents are also updated. In addition to new equipment, techniques, and procedures, changes in official policy regarding inspection and construction quality control are reflected in the guide specifications and standard practices manual. Finally, the documents are changed to reflect improvements which project engineers may offer from their everyday use of job specifications prepared with the guide specifications and standard practices manual.

5. The Office, Chief of Engineers, recognizing the need for periodic review and revision of the guide specifications and standard practices manual, provided funds for inspection trips to ongoing CE airfield and heliport paving projects to observe construction practices and to review job specifications. In a letter* to WES dated 28 April 1975, six projects where construction was planned were identified. The projects were scheduled for calendar year 1975 but one was not started until calendar year 1976.

Purpose

6. Field observation of a PFC project at Scott AFB was undertaken to observe application of the proposed mix design and specifications by a district element of the CE and to provide comments on the observed construction and materials.

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* Letter, Subject: "Inspection of Airfield Pavement Projects," to U. S. Army Engineer Waterways Experiment Station (WESSV) from Office, Chief of Engineers (DAEN-MCE-D), dated 28 Apr 1975.

7. Field observations were undertaken at five projects for observation of PCC pavement construction. The purpose of the observations of PCC pavement construction was to determine if current construction practices were compatible with present paving specifications and to recommend changes to the current guide specifications and the current standard practices manual.

Scope

8. Inspection trips were made to projects at the following locations:

- a. Cape Canaveral, Florida.
- b. Fort Eustis, Virginia.
- c. Fort Campbell, Kentucky.
- d. Nellis AFB, Nevada.
- e. Scott AFB, Illinois (PFC and PCC).

During the visits, visual observations were made of construction practices and of the finished pavement. Limited surface-smoothness measurements were made on three of the PCC construction projects. Quality control data and supporting data from the government's quality assurance program were collected at Scott AFB on the PFC construction. Discussions were held with CE project personnel at each site to obtain their recommendations for changes to current PCC paving specifications or for input to a specification for PFC construction.

PART II: DESCRIPTION OF PROJECTS AND SIGNIFICANT OBSERVATIONS

9. In this part, the construction projects visited will be described, the construction procedures discussed, and the significant observations and comments from CE project personnel summarized. The information for each project is essentially that information contained in the trip report prepared by WES engineers who visited the projects. With the exception of the Space Shuttle Landing Facility (SSLF) and Scott AFB, only one visit was made to each project and this was during construction. For the SSLF, two trips were made during construction and one trip was made after the construction was completed. Two trips were also made to Scott AFB, one to observe the PFC construction and one to observe the PCC construction.

Cape Canaveral, Florida, June 1975

10. The National Aeronautics and Space Administration (NASA) SSLF is located at Cape Canaveral, Florida. The subgrade material is a fine, uniformly graded sand. The top 6 in.* of the subgrade was stabilized with 10 percent portland cement (Figures 1 and 2). The facility's pavements include a 15,000- by 300-ft runway (oriented north-south), an apron with an access taxiway, and a taxiway from the landing facility to the Vehicle Assembly Building. The runway pavement was constructed in twelve 25-ft-wide lanes. The center four lanes are 16 in. thick for the entire length of the runway. The four lanes in the east and west sides of the runway, exclusive of 1000 ft on the southeast corner, are 15 in. thick. The east four lanes in the south 1000-ft length of the runway are 16 in. thick where the apron access taxiway and tow-way join the runway. The apron access taxiway was constructed in four 25-ft-wide lanes and one 20-ft-wide lane and is 16 in. thick. The tow-way was constructed in two 25-ft-wide lanes and is 16 in. thick. The transverse joints are spaced on 20-ft centers and are

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

Figure 1. Rutted surface of soil cement

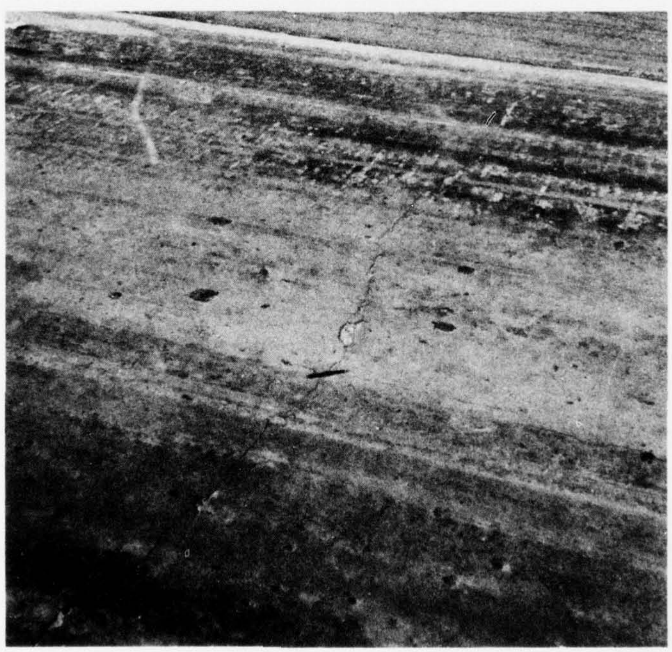


Figure 2. Shrinkage cracking of soil cement

undoweled weakened-plane types with the weakened plane formed by sawed or doweled construction joints. All longitudinal joints are keyed construction joints. The center-line longitudinal joints in the runway and tow-way, as well as the outside longitudinal joints on the runway, apron access taxiway, and apron also contain tie bars.

11. Concrete for the pavement was batched and mixed in a dual-drum Johnson central-mix plant (Figures 3 and 4). Each mixing drum had a rated capacity of 9 cu yd but only 7 cu yd were mixed because the capacity of the haul trucks was 14 cu yd. Strip recorders were used to record amounts of coarse aggregate, fine aggregate, cement, and water. The coarse aggregate consisted of two sizes: 1-1/2 to 3/4 in. and 1/2 in. to No. 4. The aggregate was a crushed limerock (from Miami, Florida). A natural sand was used for the fine aggregate. A slump of between 1/2 and 3/4 in. was maintained. Entrained air of 4 percent was specified.

12. Concrete was deposited onto the stabilized subgrade in front of a Guntert and Zimmerman slip-form paver from end-dump trucks. Basic components of the paver were an auger, spud vibrators, a transverse tube vibrator, a large forming plate, and a transversely oscillating screed. Keyways were formed in the slip-form edges with a metal liner. This liner was shaped on the paver and when tie bars were required, holes were punched into the metal liner. Bent tie bars were inserted at the front of the paver (Figures 5-9). For untied joints the metal liner remained firmly in place even though no bent tie bars were inserted at the front of the paver (Figure 10). Handwork was limited to hand floating about 4 ft along each edge to draw some mortar to fill small voids and repair low spots, and cleaning up excess mortar spilled over the edges by the tube float (Figure 11). The machine with the tube float also carried a brush which was used to apply a longitudinal brushed texture to the plastic concrete (Figure 12). White pigmented curing compound was applied for curing. The weakened planes for the contraction joints were sawed within 12 hours after placement.

13. The specified 80 percent flexural strength of the concrete was 680 psi at 28 days and 750 psi at 90 days. The concrete mix proportions per cubic yard developed by Law Engineering for the contractor are as follows:

Figure 3. Overall view of central-mix plant

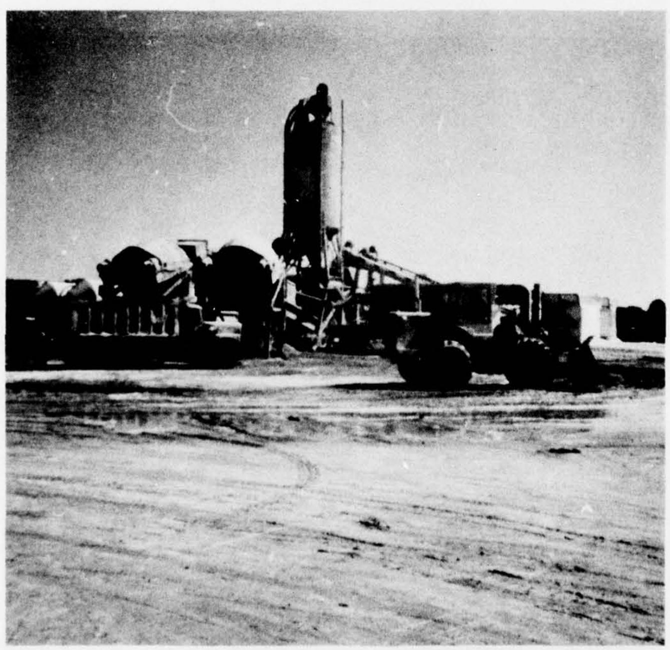


Figure 4. View of dual-drum mixers

Figure 5. Front view of Guntert and Zimmerman paver

Figure 6. Splice in keyway liner material

Figure 7. Changing reels of keyway liner material

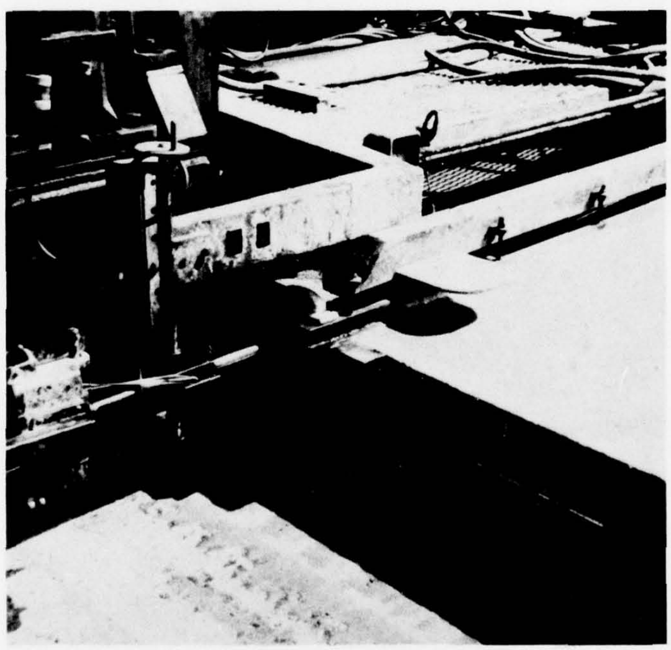


Figure 8. Edge of paving lane as formed by paver

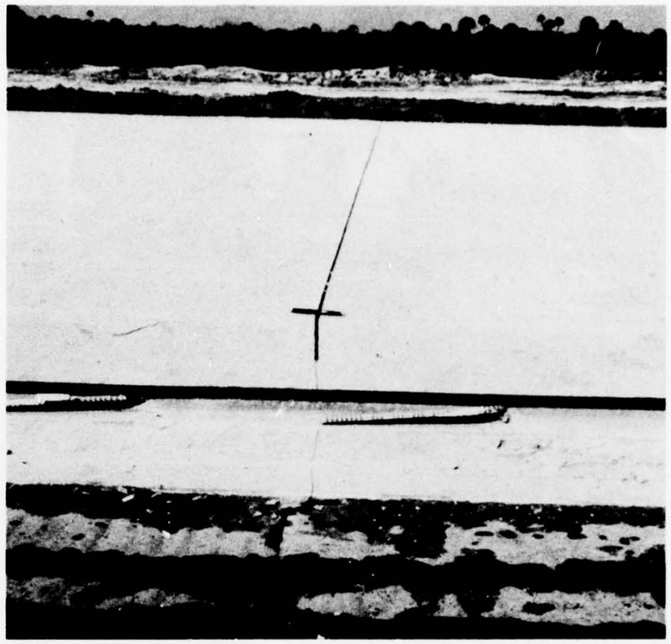


Figure 9. Keyed and tied longitudinal construction joint

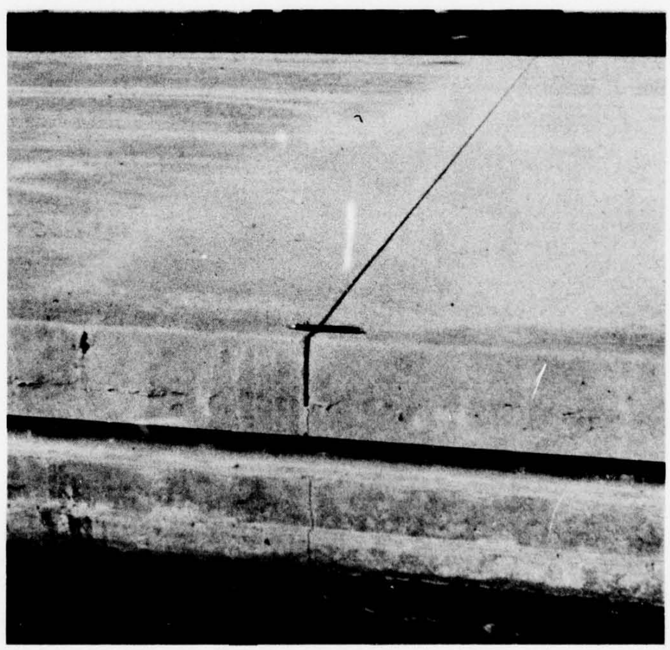


Figure 10. Keyed longitudinal construction joint

Figure 11. Floating edge of pavement

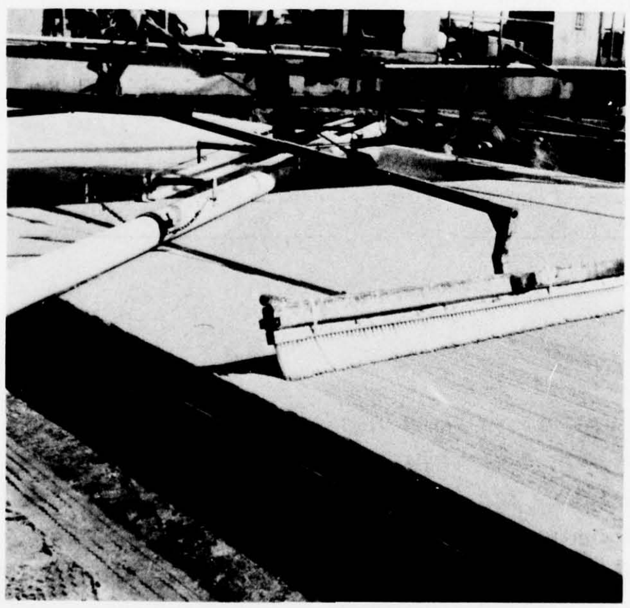


Figure 12. Application of tube float and longitudinal brush texture

Coarse aggregate (1-1/2 to 3/4 in.)	= 932 lb
Coarse aggregate (1/2 in. to No. 4)	= 944 lb
Fine aggregate	= 1118 lb
Water	= 29.5 gal
Cement	= 494 lb
Entrained air	= 4.5 percent

Upon review of the proportioning, the mix was checked by the South Atlantic Division (SAD) Laboratory, CE. Based on the SAD study, a cement content of 564 lb/cu yd (6 sacks (sk)/cu yd) was used by the contractor for the initial paving. The specifications permitted adjustments to the mix, as approved by the contracting officer, if the average of any five consecutive tests had an average strength less than the specified 680 psi. After reviewing beam breaks for the first two days placement, the contractor chose to reduce the cement content to 526 lb/cu yd (5.6 sk/cu yd). At the time of the visit, a review of the beam breaks had raised doubts as to whether or not the specified 680-psi strength could be obtained with the reduced cement content. The contractor, facing a price adjustment clause for low strength, increased the cement content to 564 lb/cu yd until more strength data could be accumulated. The job specifications contained the following price adjustment clause for less than specified strength:

28-Day Concrete Strength, psi	Pay Adjustment Downward per square yard
680-668	None
667-655	\$3.50
654-623	\$7.00
Below 623	Reject

The price reductions would be applied to areas paved using a mix design which did not meet the strength requirements. The job specifications for strength follow FAA procedures (80 percent of beams must have higher than specified strength) and result in more stringent (higher average strength and less variation) requirements than is current CE practice.

14. Surface smoothness requirements include allowable deviations from a 16-ft straightedge of 1/8 in. longitudinally and 1/4 in. transversely. Straightedge measurements were observed being made using the

usual procedures; i.e., a 16-ft metal straightedge and a scale. It appeared extremely difficult to detect deviations as small as 1/8 in. because of the rather rough (brushed) texture on the surface. However, as best as could be determined, the surface was within the limits specified except for a few areas which had been marked for correction during the first placements. Generally, the areas that did not meet specifications were at the transverse headers installed when paving stopped. It appears that a different method, preferably an automated one, is needed to check surface deviations of 1/8 or 1/4 in. in either 12- or 16-ft sections due to surface textures becoming more aggressive and even approaching 1/8- or 1/4-in. grooves or striations.

15. The job specifications stated that no more than a strip 18 in. wide along the edge of the paving lane would be affected by edge slumping and that the magnitude of the edge slump would be no more than 1/4 in. without price reduction. The price adjustment table was as follows:

Percent of Edge-Slump Measurement Between 0.36 and 0.38 in.	Percent of Edge-Slump Measurement Between 0.38 and 0.62 in.	Price Adjustment per square yard
0-24	0-9	$0.70
29-49	10-24	$2.10
50-74	25-49	$4.20
75-100	50-74	$7.00

Provisions were made for determining the amount of pavement to which price reductions were applied. Edge slump measurement observation revealed that the 1/4-in. requirements were being met consistently. However, it appeared that the requirement was being met by the hand floating wherein a small amount of mortar was being worked transversely to the edge. By careful observation, a small amount of concrete slumping could be observed directly behind the sliding form, but there was no way of measuring the amount. A straightedge placed transversely across the paving lane indicated a slight depression about 12 to 24 in. from the edge as a result of the hand floating. However, measurements indicated that this depression was not more than 1/8 in. and well within

the 1/4-in. requirement. Sawcuts indicated the thickness of mortar at the edge to be about 1/8 in.

16. Observations were as follows:

- a. The paving machine made more stops than desirable, primarily because of an inadequate supply of concrete. Other problems occasionally occurred which required additional stops. One shutdown of the paver was caused by misplacement of a bent tie bar that became lodged between the sliding form and metal liner. Another problem which frequently halted the paver was failure of the connection between rolls of the metal keyway forming material.
- b. A few tie bars had become loose in some way after the paver had passed which prevented bond in the concrete.
- c. Center-line light cans which had been installed in concrete in the soil cement appeared to be quite stable and should withstand the shoving motion of the slip-form paver without misalignment.
- d. Operations at the batch plant seemed to be in good sequence; however, the movement of coarse aggregates from stockpile to storage hoppers seems to be inefficient and raises a question as to whether some segregation might occur.
- e. Observations and preliminary mixer efficiency test results indicated that the specified mixing time of 80 seconds could probably be reduced to 55 or 60 seconds.
- f. The cement-stabilized sand base was cracked about every 20 ft; however, from visual examination, it did not appear that the cracks were working extensively.
- g. It appeared that the contractor was extremely conscious of the penalty clauses for concrete strength and edge slump. It was the opinion of Corps of Engineers and Kennedy Space Center personnel that the strength penalty clause was instrumental in the contractor increasing the cement content on his own and subsequently making a thorough study of the mix proportions to achieve the specified strength. Without this, the requirement falls upon the contracting officer.
- h. All in all, this appeared to be one of the best slip-form paving jobs visited.

17. Based on discussions with CE and contractor personnel and on observations during this visit, conclusions are as follows:

- a. The concrete strength, slump, and air content should be specified, and the contractor allowed to select a mix

design using approved materials. This will be a step toward end product specifications and will be consistent with recent trends toward contractor quality control, price reductions, and CE inspection and control of paving jobs.

b. It appears that smoothness requirements which are more realistic than the deviations from a 16-ft straightedge are needed, or that a better measuring instrument must be devised. The rougher surface textures now being specified make the detection of 1/8-in. deviations difficult, if not impossible.

c. The transverse hand float appears to be a satisfactory way of compensating for edge slump; however, a study of the effect of the mortar on edge durability is urgently needed. This could be evaluated by freeze-thaw and wet-dry type tests.

d. The inclusion of a strength requirement for the joints in the metal keyway forming material is needed in the specifications to assure that failures of the joint do not result in excessive paver shutdown.

Cape Canaveral, Florida, August 1975

18. A second visit was made to Cape Canaveral about two months after the initial visit to further observe the construction of the pavement for the SSLF.

19. Joint sealing operations were just beginning on the job. Neoprene compression seals were to be used in all joints. The sequence for placing the seals was to place the seals in all the longitudinal joints and then to cut the seals at the intersection of transverse joints. The seals were then placed in the transverse joints. We were not able to observe the sealing operations but the approximately three quarters of one longitudinal construction joint which had been sealed looked very good. Longitudinal construction joints are normally the most difficult to seal, but project personnel indicated that they had not experienced any unusual difficulties. This was probably because the sawed groove was straighter than normal and the close control and special efforts made to match the edges minimized problems normally encountered with longitudinal construction joints. The seal was

installed to a uniform depth and project personnel indicated that they were able to keep the stretch well within the manufacturer's recommended tolerances. The joint sealing subcontractor had fabricated a self-propelled device for cleaning the groove. This was simply an air compressor with a tracking mechanism to which a motor was mounted for driving a steel brush. The steel brush was used to loosen the material in the groove and high pressure air was then used to remove it. The cleaning device was followed by the machine for inserting the seal.

20. Based on the results of mixer performance tests, the mixing time for concrete had been reduced from the originally specified 80 seconds to 59 seconds. Larger trucks (16 cu yd) had been obtained and the batch size increased from 7 to 8 cu yd.

21. In the description of the initial visit it was noted that a brush was being used to texture the surface. This was now being used in the finishing operations. Tears and small depressions were being formed in the surface, and the brush was being used in conjunction with the tube float to move mortar around on the surface to fill these tears and depressions (Figures 13 and 14). The brush was moved back and forth several times over the surface, rather than only one time which is all that is necessary for texture application, and considerable mortar resulted as shown in Figure 14.

22. During this visit a paving lane was being placed adjacent to a previously placed lane resulting in only one free edge. Hand finishing along the free edge was limited to hand floating about 4 ft along the edge to draw mortar toward the edge, filling low spots, forming the edge with an edging tool, and removing excess mortar spilled along the edge. Along the fill-in edge a similar strip was hand floated and the mortar worked toward the edge. Its use here was also to fill in the low spots and to provide a smooth transition between the paving lanes (Figure 15). It appeared that the finishers were somewhat overzealous in their efforts to match the edges of the paving lanes and as a consequence were overworking the fill-in edge. This was confirmed by straightedge measurements which indicated that high spots were being built along the edge of the fill-in lanes.

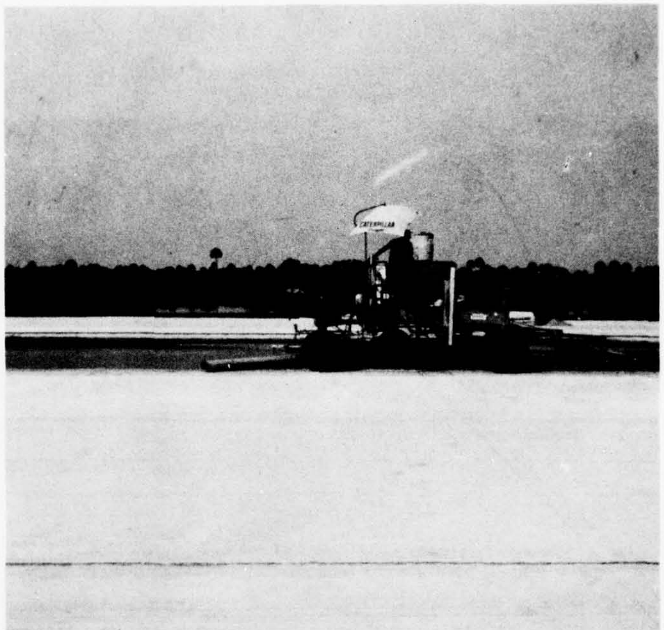


Figure 13. View showing pavement finishing (note both tube float and brush)

Figure 14. Closeup view of brush applying finish texture to pavement

Figure 15. Finishing operations between paving lanes

23. During the last visit it was noted that the contractor had started with a high cement content, but as strength data were accumulated, indicating that strengths larger than those required were being obtained, the cement content was reduced. The cement content of the mix recommended by Law Engineering was 494 lb/cu yd (5.25 sk/cu yd). A number of mixes were tested by the SAD Laboratory and, based on the strength gains and strengths obtained, a mix with a cement content of 564 lb/cu yd (6 sk/cu yd) was selected. Apparently some of the discrepancies between the results obtained by Law Engineering and the SAD Laboratories were caused by differences in methods for preparing aggregate and differences in the workability of the mixes. Paving was started with a 564 lb/cu yd (6 sk/cu yd) mixture. The cement content was reduced after several days to 526 lb/cu yd (5.6 sk/cu yd), increased back to 564 lb/cu yd (6 sk/cu yd), decreased to 540 lb/cu yd (5.75 sk/cu yd), decreased to 526 lb/cu yd (5.6 sk/cu yd), and finally decreased to 508 lb/cu yd (5.4 sk/cu yd). The 5.4 sk/cu yd mix was

being used at the time of this visit. Adjustments to the aggregate proportioning were also made as the cement contents were adjusted.

24. The manner in which the concrete strength was controlled on this job, as compared to the procedures outlined in MCGS 02611[3] and TM 5-822-7,[4] leads to some rather interesting speculation as to the "best" way to control concrete strength. If the assumption is made that all contractors have access to the same sources of materials and that the "best," or at least the same sources of materials will be selected by all contractors then some comparisons can be made. The acceptance by the contractor of the responsibility for obtaining the required strength (with a payment adjustment clause as an incentive) can lead to situations where a savings could be realized by the government, or to situations where the government could save money by accepting the responsibility for the concrete strength and paying for the cement separately as outlined in MCGS 02611[3] and TM 5-822-7.[4] The situation that develops will depend on the actions of the contractors bidding on the job. If all of the bidding contractors perform complete mix design studies to obtain the optimum mixture proportions (while simulating field conditions and while also considering the variability of the material which will occur and workability requirements) the procedure employed should result in a savings for the government. This should happen since the contractor with the most efficient (lowest) cement content should receive the bid. Although the cement content will probably be increased somewhat for bid purposes, if the contractor has developed an accurate strength-gain-with-time relationship, overestimating should be kept to a minimum. This procedure should, therefore, stimulate competition among contractors to select the most efficient proportions of available materials, and to control the variability of the concrete in order to keep cement requirements to a minimum.

25. Straightedge measurements were made with a 16-ft straightedge provided by the inspectors. This straightedge had wheels mounted on each end with a 1/8- to 1/4-in. gap between the bottom of the wheels and the bottom of the straightedge. The straightedge was not a precise

measuring tool because of the "slack" in the wheels and the flexibility of the straightedge, but it was a rather quick way to locate areas of large deviations. Considering the surface texture the straightedge was probably adequate. Rolling the straightedge across the runway revealed a very uniform surface. Of the portion of the pavement checked, which consisted of the six interior paving lanes near the center of the runway, no locations were found where the bottom of the straightedge actually touched the surface, indicating no locations where the surface deviated more than about 1/8-1/4 in. from the 16-ft straightedge. Rolling the straightedge along the runway revealed a number of locations where the bottom of the straightedge touched the surface. Upon more detailed examination only two or three locations were found where the 1/4-in. tolerance was exceeded. All of the locations where the straightedge touched were along longitudinal construction joints and in particular the joint west of the pavement center line. The joint east of the center line had only a few locations where the straightedge touched. The surface along this joint was indistinguishable from the paving lane interiors (Figure 16). However, along the joint west of the center line two distinct surface profiles were noted. Both were probably caused by the hand-finishing operations. These are shown in Figure 17.

26. The profile in Figure 17a was probably caused by pulling mortar to the slip-form edge to compensate for the edge slump. Then, during the fill-in operations, the fill-in edge was overbuilt, producing the ridge along the fill-in edge (Figure 18). The shape illustrated in Figure 17b is the more conventional shape with the slip-form edge showing some evidence of edge slump while the fill-in lane is flatter (Figure 19). Fill-in edges are usually higher as a result of manual finishing.

27. This visit produced no evidence to warrant major revisions of the conclusions drawn from the initial visit. The straightedge measurements reinforce the conclusion that more realistic tolerances and a better measuring device are needed for surface smoothness control.

Figure 16. Straightedge measurement across longitudinal construction joint

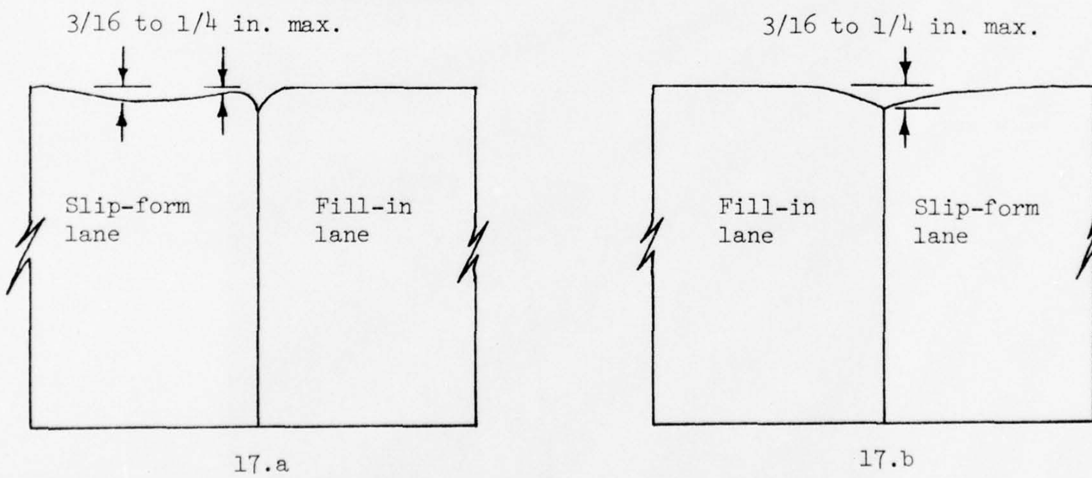


Figure 17. Typical surface profiles along longitudinal construction joints

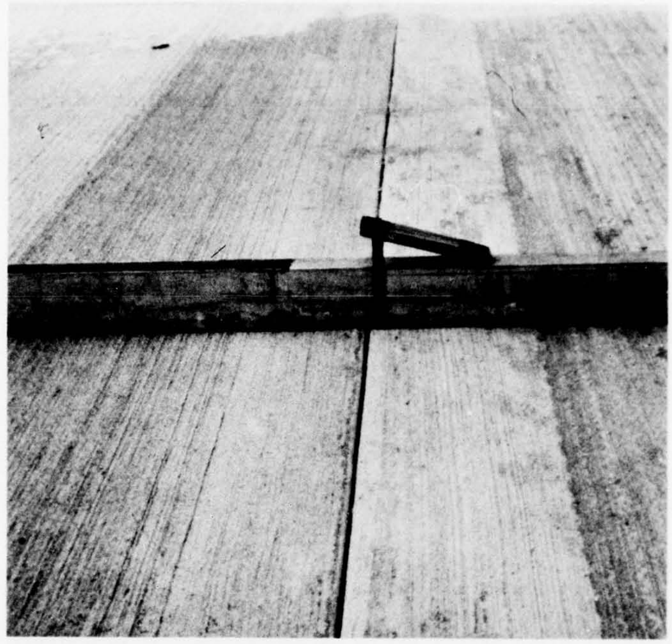


Figure 18. Typical shape along longitudinal construction joints (ridge along fill-in edge)

Figure 19. Typical shape along longitudinal construction joints (fill-in lane flatter)

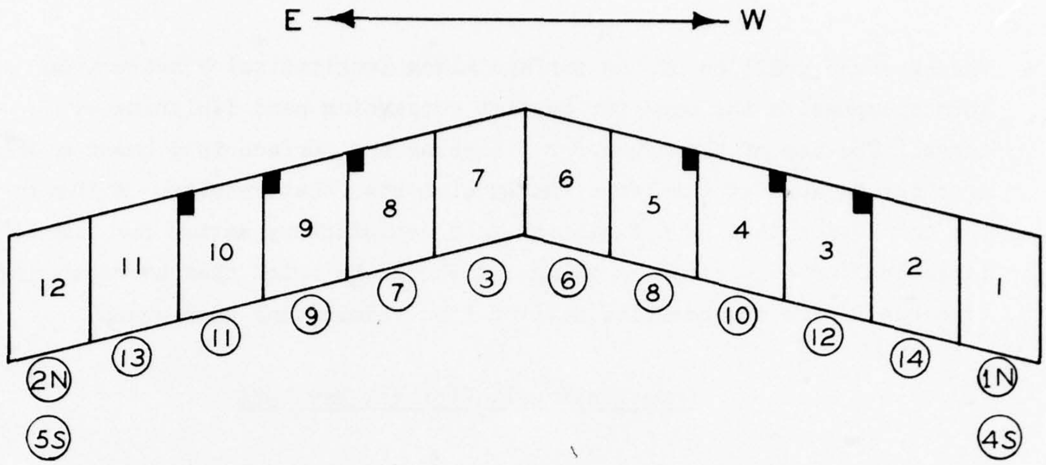
The observed profiles of the surface along longitudinal construction joints emphasize the need for caution concerning hand finishing of edges. The use of the brush for finishing the surface is a questionable practice because of the large amount of mortar that results. Although the conclusion that hand finishing is a satisfactory method for compensating for edge slump is valid, it should be noted that overcompensation can negate any benefits derived from eliminating edge slump.

Cape Canaveral, Florida, May 1976

28. At the request of NASA, an inspection of scaling along longitudinal joints at the SSLF was made on 4 May 1976. Scaling or flaking of the concrete surface along longitudinal construction joints was first noticed in March 1975 during surface grooving operations. This was several months after completion of the pavements construction. A detailed survey was conducted at that time by the CE Project Engineer. This survey indicated that the scaling varied from paper thin to a maximum of 1/4 in. deep and extended up to 4 or 8 in. from the joint. The scaling occurred randomly along only slip-formed edges and extended in length from a few inches to as much as 20 to 25 ft. No scaling was detected on slab edges that had not been slip-formed (fill-in lanes) nor had any scaling occurred on pavement surfaces that had not been grooved irrespective of placement method (i.e., outside edges of the outer lanes of the runway and all apron and tow-way pavements). It was reported that 200± linear ft of scaling had occurred in the total of 330,000 linear ft of longitudinal slab edge on the runway or about 0.06 percent.

29. During construction of the SSLF two visits, described previously, were made to observe construction practices. A review of the pertinent practices observed is as follows:

- a. The 300- by 15,000-ft runway was paved with twelve 25-ft-wide paving lanes using a slip-form paver operating on a cement-stabilized sand base. The placement sequence is illustrated in Figure 20. Lanes 1, 12, and 7 were placed with both edges slip-formed. Lanes 3, 4, 5, and 6 were



■ Scaling observed along joint.

7 Paving lane number.

(3) Construction sequence (north half of lane 1 placed first, north half of lane 12 placed second, lane 7 placed third, south half of lane 1 placed fourth, etc.).

Figure 20. Construction sequence and location of spalling

placed with the west edge being slip-formed and the east edge formed by placement against the previously placed concrete. Likewise, lanes 8, 9, and 10 were placed with the east edge being slip-formed and the west edge formed by placement against the in-place concrete. Lanes 2 and 11 were final fill-in lanes with both edges being formed by placement against the in-place concrete.

b. The concrete placement sequence used for the apron pavement was slightly different. On the apron, alternate paving lanes were first placed with both edges being slip-formed. The edges of the fill-in lanes were thus formed by placement against the in-place concrete.

c. Conventional (state-of-the-art) construction procedures were used throughout the job. The slip-form paver was a Guntert and Zimmerman machine with the normal components plus a transversely oscillating screed behind the forming plate. Behind the paver, operations consisted of some handwork along the edges followed by a tube float, longitudinal broom texturing, and application of curing compound. Transverse joints were sawed within 12 hours after

concrete placement. The handwork along the edges immediately behind the slip-form paver consisted of hand floating about 4 ft along each edge to draw a little mortar toward the edge, repair of small voids and low spots along the edge using mortar and a metal right-angle edging tool, and cleaning up excess concrete slurry spilled over the edges of the slab or onto the adjoining concrete by the finisher and the tube float operation. The edges were checked with a straightedge to determine compliance with job specifications which permitted a maximum of 1/4-in. edge slump without a reduction in payment. Areas exceeding the 1/4-in. slump were reworked by hand to bring them within specified limits. Normally, all handwork occurred immediately behind the paver, prior to tube floating and surface texturing, while the concrete was still in a plastic state.

d. The runway pavement surface was grooved transversely following construction. The grooves, 1/4 in. wide by 1/4 in. deep on 1-1/8-in. centers, were sawed in the pavement surface across the width of the runway, beginning and ending about 10 ft from each edge.

30. As a result of the two visits, it was concluded that the construction practices were good and that, all in all, this appeared to be one of the best slip-form paving jobs visited. However, the following summary of the reports of both visits may be pertinent to the scaling that has occurred:

a. The transverse hand float appears to be a satisfactory way of compensating for edge slump; however, a study of the effect of the mortar on edge durability is urgently needed. This could be evaluated by freeze-thaw and wet-dry type tests.

b. Hand finishing along the free edge is limited to hand floating about 4 ft along the edge to draw mortar toward the edge, filling low spots, forming the edge with an edging tool, and removing excess mortar along the edge. Along the fill-in edge, a similar strip was hand-floated and the mortar worked toward the edge. Here it was used to fill in low spots and used to provide a smooth transition between the paving lanes. Finally, a groove was formed between the paving lanes. It appeared that the finishers were a little overzealous in their efforts to match the edges of the paving lanes and as a consequence were overworking the fill-in edge.

c. Although the conclusion that hand finishing is a satisfactory method for compensating for edge slump is valid,

it should be noted that overcompensation can negate any benefits derived from eliminating edge slump.

The above indicates a concern regarding the durability of the mortar or mortar-like material used to build up the slab edges to compensate for the slumping that characteristically occurs in the plastic concrete following slip-form paving.

31. The inspection performed on 4 May 1976 confirmed the condition observed in the CE Project Engineer's survey of March 1976. Scaling was limited to the slip-formed edge of paving lanes 3, 4, 5, 8, 9, and 10 as shown in Figure 20. No scaling was noted along the slip-formed edges of paving lanes 1, 6, 7, and 12 or along the edges of fill-in lanes 2 and 11. Nor was any scaling noted along either slip-formed or fill-in edges of the ungrooved apron and tow-way pavements. The scaling had occurred randomly along the edges and in random lengths ranging from a few inches to several feet. The depth of the scale varied from paper thin at the edge to a maximum of about 1/4 in. and generally featheredged out 4 to 8 in. from the edge. The scaled material was a sand-cement mortar containing no coarse aggregate. The surface exposed by the scaling was very smooth with a characteristically different color (lighter) from the scaled material. A scraping device had been used to remove weakened mortar material that had not been dislodged by the groove-sawing operation. However, additional mortar material could be broken loose with a knife blade or by tapping on the surface with a steel rod. Tapping with a steel rod confirmed that the condition leading to the scaling is probably random, because sound concrete could be detected at the boundaries of the scaled areas. Particular attention was paid to the unscaled edges of the runway and apron; however, tapping with the steel rod did not reveal any conditions (hollow sound or crushing of the mortar surface) that would indicate a potential for future scaling. Based upon the visual inspection, sounding of the concrete with a steel rod, review of material quality and handling techniques, and a review of construction practices, there is no reason to question the overall quality of the concrete pavement. All indications are that the scaling is a localized problem randomly located along a portion of the longitudinal joints.

32. Facts relative to the scaling problem are as follows:

a. The scaling problem exists only on slip-formed edges indicating a relationship with slip-form construction procedures. Similarly, the fact that scaling has occurred only along edges of pavements that have been grooved indicates a relationship to the grooving operation. However, neither all slip-formed edges nor all edges that have been grooved have scaled, pointing to some other condition as the basic cause of scaling.

b. The random occurrence and the general configuration of the scaled areas strongly suggest that the scaling is associated with the hand working along the edges to compensate for slumping of the unsupported plastic concrete. There are two facts that are considered pertinent. First, the depth of the scaled areas rarely, if ever, exceeded 1/4 in. (the maximum amount of edge slumping permitted by the job specifications without a reduction in pay). Therefore, either the total amount of slump exceeded 1/4 in. and the repair was to bring the edge back to specification limits without a reduction in pay or if the initial slump was 1/4 in. or less, the repair was made primarily to simplify finishing of fill-in lanes to be placed later. The second pertinent fact is the absence of scaling in the initially placed lanes on the runway. This suggests that either the requirement to build up the slumped edge to meet specification requirements was more rigidly enforced in the latter lanes or the contractor realized that finishing operations on lanes abutting in-place lanes were simplified if the edges of the in-place lanes were built up to specified grade (no slump). In either case, it appears that there was more effort applied to repair or build up the edges of the slip-formed edges after completion of the first four or five paving lanes. This could have resulted in more handworking of the edges which increased the likelihood of excessive mortar buildup and/or late edge finishing which resulted in a weak edge condition. The aggressive sawing action then caused the weakened-edge condition to scale.

33. Based upon the inspections, review of construction practices, and information regarding materials quality and handling techniques, it is concluded that the scaling is related to, but not directly caused by, the slip-form or groove-sawing operation. Rather, it is probably the result of one or more of the following:

a. Excessive and/or late handworking of the slip-formed edges to compensate for excessive slumping of the unsupported plastic concrete behind the slip-form paver. Excessive working of the edges can cause displacement of the coarse

aggregate leaving a poor quality mortar surfacing which does not exhibit sufficient strength to withstand aggressive loading such as the groove-sawing operations. Improper use of the tube float and repeated passes of the broom for applying surface texture also result in concentration of weak mortar along longitudinal construction joints. The late repair of slumped edges results in the application of a mortar material to the concrete after it has experienced its initial set. This results in a weak bond between the concrete and mortar surface which cannot withstand aggressive loadings.

b. The incomplete removal of plastic concrete deposited on the surface of hardened concrete during the construction of a paving lane abutting an in-place paving lane. Normal practice is to scrape and/or sweep the deposited material from the hardened concrete; however, any not removed will exhibit weak bond to the existing concrete and is highly susceptible to flaking or scaling.

34. The groove-sawing operations produced an aggressive action which caused a separation of the mortar surfacing from the underlying concrete along the joints. Whether the scaling would have occurred had the pavements not been grooved is open to conjecture. Considering the relatively low strength of the spalled mortar material and the low bond strength between the mortar and concrete, it is probable that some scaling would have occurred due to stresses created by wheel loadings and/or climatic changes. Certainly, the integrity of the edges would be suspect in more aggressive climates where freezing and thawing of the pavements would occur. While not as severe, repeated wetting and drying of the concrete surface will cause stresses which, when added to wheel load stresses, may create conditions that exceed the mortar and/or bond strength. Considering these possibilities, it is probable that some additional scaling will occur randomly along the longitudinal joints including the joints in pavements that have not been grooved. The amount of any longitudinal scaling cannot be determined. It may be possible to better quantify the amount by tests of the concrete integrity along the joints. Meanwhile, it is felt that the major portion of scaling that will occur on the runway has already taken place during the groove-sawing operation. While some additional scaling may occur, it will probably be less than has already occurred and it should happen at a relatively slow rate.

35. The following alternatives regarding remedial measures were discussed at the conclusion of the field inspection:

a. If it is determined that scaling does not present an operational problem, no remedial measures should be taken at this time. Some additional scaling, random in nature and probably less extensive than has already occurred, should be anticipated. This will necessitate surface cleaning to remove debris produced. The scaling should diminish with time; however without more extensive testing, it is impossible to estimate how much more will occur or when it will cease.

b. If the scaling is not an operational problem but the debris produced by it is determined to be an excessive housekeeping problem, it might be possible to accelerate the scaling and remove it prior to operations. This would only reduce future maintenance (cleaning) requirements. Although untried, it is believed that trafficking along the longitudinal joints with a few passes of a heavily loaded, narrow solid-rubber-tired or steel-wheeled vehicle (such as a forklift) would loosen potentially scalable material which could then be removed and lessen the potential for foreign object damage in future operations.

c. If the scaling is determined to be an operational problem or for other reasons it is desirable to repair the scaled edges, such repairs can be made using either an epoxy bonded PCC or epoxy concrete patches. It will first be necessary to carefully determine the scaled and potentially scalable areas using either (1) visual examination, (2) the solid-rubber-tired or steel-wheeled traffic mentioned in b above, or (3) a Schmidt hammer, or a "sonescope" as will be discussed in the following paragraphs. After delineation of the areas to be repaired, it is recommended that the repairs be made with epoxy mortar or concrete.

Experience has shown that repairs such as those that would have to be made to correct the scaled or potentially scalable areas at the SSLF can be made, and that they will perform satisfactorily. However, it must be pointed out that there would be the potential for additional scaling in areas not detected in the delineation of areas for repair and the loss of bond between the patch and parent concrete either of which would result in the need for additional maintenance in time.

36. While the quality of the concrete along the edges of the paving lane can be checked by a destructive means, such as a rolling wheel or

some type of impact hammer which would fracture weak concrete, any quantitative measure of the concrete quality by available nondestructive tests in the field is difficult. It may be possible to make qualitative (or comparative) measures of the concrete quality using instruments such as the rebound hammer (Test Method CRD-C-22-74[5]) or the ultrasonic pulse velocity apparatus (Test Method CRD-C-51-72[5]). These instruments are briefly described as follows:

a. The rebound hammer test is based on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges. The rebound hammer (commonly known as the Schmidt hammer) consists of a spring-loaded mass which when triggered imparts a fixed amount of energy to the concrete surface. The rebound of the mass, which is measured by a graduated scale, is a measure of the concrete quality upon which the mass impinges. Thus the measurement should detect significant changes in the quality (strength) of any one mix proportioning such as that used for the SSLF. The questionable aspects of the test are whether the thin mortar surfacing (1/8 to 1/4 in.) and/or weak bond strength between the mortar and underlying quality concrete would have enough effect on the rebound measurement to indicate a significant difference.

b. The ultrasonic pulse velocity test is used to measure wave velocity in concrete which is a measure of the concrete quality (density). This type test is commonly used in the laboratory to measure concrete quality (modulus of elasticity), or more importantly to measure changes in concrete quality when evaluating the durability of the concrete. An adaptation of this test has been used to nondestructively measure the quality of concrete in the field. The equipment consists of a transmitting transducer which emits vibrations to the concrete and a receiving transducer which is placed at a known distance from the transmitting transducer. The time required for the vibrations to travel through the concrete from the transmitting to receiving transducers is measured and used to compute the wave velocity. The wave velocity is then relatable to the quality (density) of the concrete or it can be used to compute the modulus of elasticity of the concrete. These relationships have been found to be fairly reliable for any one concrete mix proportioning and thus can be used to detect differences in concrete quality for any one concrete mix such as that used for the SSLF. There are, of course, many factors other than density which can affect the wave velocity in concrete, such as cracks,

minute fractures, weak bond of cement paste to aggregate, etc., and these must be considered when interpreting the results of wave velocity measurements.

c. Ultrasonic pulse velocity tests and rebound hammer tests were conducted on 12 May 1976. It was impossible to detect areas with weak mortar layers on the surface with the ultrasonic velocity tests. No differences could be detected between the velocity measurements on scaling areas and sound areas. The following tabulation shows experimental velocity measurements at SSLF stations 64+20 to 64+40:

Lane 5, Near Joint Between Lanes 4 and 5

Path Length ft	Velocity, fps Scaling Area	Good Area
3	13,700	13,825
6	13,485	13,665
8	13,400	13,400

Note: Signal amplitudes were all equal.

It was felt that any weak surface layers present were too thin to affect the wave velocity and amplitude measurements. Measurements with the rebound hammer were generally smaller along lane edges indicating lower strength concrete in these areas (Tables 1-3). During the testing and data analysis several important factors were noted. It was determined that the paint which contained small glass beads and rough surface texture decreased rebound readings. Paint was more prevalent along the edges and the surface texture along the edges was rougher. These may have been the primary reasons for the lower average readings along the edges rather than the presence of low strength mortar on the surface. There was also no direct comparison between the rebound loadings and scaling or sound areas. For these reasons the results from the rebound hammer tests were considered inconclusive.

37. The following summarization of the condition of the concrete pavements at the SSLF is based on this inspection, previous inspections by WES personnel, review of pertinent construction and quality control data, and discussions with project personnel along with recommendations pertaining to applicable remedial measures.

a. There is no reason to suspect the overall quality of the concrete within any of the paved areas at the SSLF.

Since the overall quality of the concrete is not suspect, the structural integrity of the pavements is likewise not suspect.

b. The scaling that has occurred randomly along the longitudinal edges (about 0.06 percent of the total longitudinal slab edge) is believed to have resulted primarily from late handworking to build up the edges of the plastic concrete which slumped during the slip-forming operations.

c. The aggressiveness of groove sawing is believed to have caused the spalling of the majority of the weak edge condition. While some additional scaling should be anticipated, it is believed that the major portion of runway scaling has already occurred during the groove-sawing operations.

d. It is believed that because of the inherent weakness of the bond between the mortar and parent concrete, the probability is good that some scaling would have occurred had the surface not been grooved. This leads to the possibility of some future scaling in the ungrooved apron and tow-way pavements. However, any such scaling would occur randomly and probably far less extensively than it has occurred on the grooved runway.

e. Unless the scaled areas present an operational problem it is recommended that no repairs be attempted at this time. It is believed that the scaling will cease and that the pavements will function properly from a structural standpoint. Additional scaling may require some housekeeping in the form of vacuuming and sweeping to remove debris from the surface.

f. If it is determined that the scaling presents an operational problem, it is recommended that the potentially scalable areas be delineated and repaired by cutting and chipping out about 1- to 2-in. depth of concrete along the edge and patching with an epoxy concrete material.

g. The results from the ultrasonic velocity tests indicated that the tests could not be used to delineate potential scaling areas. The results from the rebound hammer tests were inconclusive as to applicability of the tests for delineating potential scaling areas.

Ft. Eustis, Virginia, October 1975

38. An aircraft parking apron, consisting of approximately 67,000 sq yd of rigid pavement and 20,000 sq yd of flexible pavement,

was constructed at Felker Army Airfield, Ft. Eustis, Virginia. The PCC was placed by the slip-form method. The PCC pavement was 7 in. thick. Each paved lane was 25 ft wide and a longitudinal weakened-plane joint was sawed along the center line. Transverse joints were sawed at 15-ft intervals, thus forming 12-1/2- by 15-ft slabs. The outside longitudinal construction joints were tied with 30-in. No. 5 rebars, and spaced on 30-in. centers. All other longitudinal joints were doweled with 1-in.-diam, 16-in.-long dowels. The formed end slabs are joined to the slip-formed slabs with a standard doweled transverse construction joint. Thickened-edge butt joints, 9 in. thick, were designed to allow for future construction.

39. Concrete was batched and mixed in a dual-drum Rex central mix plant. Each drum had a 9-cu-yd capacity. The concrete haul-trucks were of the end-dump type. The slip-form paving train was made up of CMI equipment. In the concrete mix design for this project there were two types of additives used in the paving mix: an air-entraining admixture, and an additive used to ensure workability of the plastic concrete. A 6.25-sk/cu-yd mix was used. A maximum slump of 2 in. was maintained, and entrained air between 3-1/2 and 6-1/2 percent was specified. The required characteristics of the cured slab included a design flexural strength of 600 psi at 28 days.

40. At one point early in the paving, an excessive air content was detected in two or three batches of concrete. The concrete had already been placed, so it was torn out and replaced by the contractor. No other significant batch plant problems had been identified at the time of this visit. The first major construction problem was obtaining the specified density of the subbase material. One possible contributing factor is the fact that the subbase is a sand and therefore susceptible to bulking, etc., under roller-type compaction. However, a vibratory roller was used, so reasonably good compaction could be expected. Wet, rainy weather could be blamed for much of the density problem. A second major problem involved placement of the dowel bars along the longitudinal construction joint faces. A hydraulic ram assembly was attached to the slip-form paver which pushed the dowels into the joint face at the

prescribed spacing. The ram pushed the dowel in through an opening in the slip-form plate at a point about 3 ft from the rear end of the plate. A slot had been cut in the plate from the point of entry of the dowel bar to the rear end of the plate to allow passage of the implanted dowel bar as the paver moved along in the forward direction. The slot was about 1-1/4 in. wide. The first paving was attempted allowing the machine to work automatically, but construction personnel noticed that the wet concrete accumulated in the slot behind the dowel bar insertion point and caused excessive drag forces on the dowels. This caused the dowels to be left with an acute angle between the dowel and the joint face in the forward paving direction. This condition was corrected by positioning a man with a shovel at each hydraulic ram position to keep the slot clear of concrete buildup. One other significant construction problem concerned the finishing of the second lane paved. The dual tube-float consists of a short tube section which, when used at an angle of approximately 60 deg with the longitudinal axis of the pavement lane, extends about 2 ft past the center line from the right edge of the paved lane (facing the forward paving direction), and a long, full-width diagonal second tube. The shorter tube section was set slightly off the finish surface grade in such a way as to cause the end near the lane center line to gouge a groove the length of the second paving lane. The groove varies in depth from about 1/16 to 1/4 in.

41. In addition to the surface defect caused by the tube float, virtually all of the dowels on both sides of the third paved lane slope downward at about 10 to 20 deg from the horizontal for about two-thirds of the lane length. On first observation of the sloping dowels, one might think that the slump of the concrete was high enough to allow the dowels to gradually sag downward after placing. However, that is probably <u>not</u> the case here. There is no evidence of excessive edge slump of the concrete itself and there are no "bumps" in the surface of the concrete over the inside ends of the dowels as might have been expected if the dowels had sagged downward after placement. Also, at the point where the dowels enter the formed face of the pavement there are no slump-tears immediately above the dowel bars in their present position.

If the bars had sagged downward after placement, these tears would probably be present. No probable cause nor possible explanation is speculated, but it seems that the dowels in this particular section of paving were initially placed in the downward sloping position.

42. A general discussion was held with personnel at this job site and below is a summary of their comments and conclusions regarding the job:

- a. The consensus among CE personnel here was that cement should not be a separate pay item in the contract for small paving jobs. They suggest payment per unit of concrete pavement in place, either by area or volume.
- b. A separate set of guide specifications for "small" jobs would be very useful.
- c. The hydraulic ram method of inserting the dowels through the side-forming plate on the paver appeared to have worked well after the "bugs" were worked out of the system. No measurements had been made, nor were planned, to check the alignment of the dowels, and the determination of adequacy was based on visual inspection. Paragraph 22.5, Dowels and Tie Bars--Fixed Form Installation, of MCGS 02611[3] gives tolerances and calls for "an approved template for checking the position of the dowels." No mention of either is made in paragraph 22.6, Dowels and Tie Bars--Slip-Form Installation. Since installation of dowels in longitudinal construction joints is a major problem with slip-form pavers, the long-term performance of the joints should be monitored to assess the adequacy of the construction techniques.

Fort Campbell, Kentucky, October 1975

43. A helicopter parking apron and other appurtenances were constructed at Fort Campbell, Kentucky. The paved area totaled approximately 143,690 sq yd. Forms were used. Each paving lane was 25 ft wide, 7 in. thick, and a longitudinal weakened-plane joint was sawed along the center line. Transverse contraction joints were also sawed at 15-ft intervals, forming a 12-1/2- by 15-ft slab. The outside longitudinal construction joints were tied with 30-in. No. 5 rebars spaced 30 in. center-to-center. All other longitudinal construction joints were thickened-edge (8-3/4 in.) butt joints untied and not doweled.

The dowels used in the standard type transverse construction joints were 3/4-in. diameter, 16 in. long and spaced 12 in. center-to-center.

44. Concrete was batched and mixed in a 9-cu-yd Rex central mix plant and hauled to the paving site in 9-yd Maxon side-dump trucks. Two sizes of crushed limestone aggregate were used. An average slump of 2 in. was maintained. Entrained air of 3 to 5 percent was specified. The required design flexural strength of the cured slab after 28 days was 650 psi.

45. The paving train consisted of three pieces of equipment. First was the Maxon spreader, designed for use with side-dump haul trucks. Then came a screed-finisher with a burlap drag texture device. Last in the paving train was a spray-bar distributor for applying the curing compound.

46. A delay was encountered because no strip recorder equipment was on the batch plant. This equipment had to be procured and incorporated into the plant. This is often a problem since only CE requires records. After operations had begun, several delays were caused by the various pieces of equipment in the paving train breaking down. The paving equipment was old and appeared to be in poor condition. However, after numerous false starts and delays the contractor managed to make the necessary repairs and adjustments and paving proceeded. One major problem that was noted in the first two lanes was the transverse construction joints; both at the ends of paving lanes and within lanes where work stoppages occurred. These joints were doweled as described before, and extensive spalling and concrete breakage had occurred around each dowel. The cause of this is not known for certain but was apparently caused by the superintendent's inexperience in placing dowels. This situation was corrected by CE representatives and later installations appeared adequate.

47. The use of two-way radios enabled the paving train operators and paving supervisors to be in constant contact with batch plant personnel. This innovation worked extremely well in coordinating delivery of concrete to the paver.

48. Conclusions from observations and discussions with project personnel are as follows:

- a. For "small" jobs CE specifications should permit payment per unit area or volume of concrete in place and accepted, rather than separate payment for cement.
- b. Strip recorders should not be required, particularly for small jobs.
- c. The reduced testing requirements for deleterious materials contained in the latest version (1975) of the guide specifications (MCGS 02611[3]) are more realistic and more economical than in previous versions.

Nellis AFB, Nevada, November 1975

49. The PCC runway located at Nellis AFB, Nevada, is 150 ft wide and consists of 12- to 16-in.-thick pavements. The pavements were being constructed in six 25-ft-wide lanes separated by either doweled or keyed longitudinal construction joints. The thicker pavements were located along the center line of the runway and at the runway ends. The thinner pavements were located in the outer lanes. The two outer construction joints were keyed and the remaining four longitudinal construction joints were doweled butt joints. Undoweled transverse contraction joints or doweled transverse construction joints were spaced 25 ft apart. The base was a material from an old flexible pavement. The asphalt concrete surfacing was removed and about 12 in. of the existing base and subbase material reprocessed and compacted in 6-in. lifts.

50. Concrete was batched and mixed in a 9-cu-yd Rex central mix plant (Figure 21). Eight-cu-yd batches were mixed for 55 seconds after all ingredients were charged in the mixing drum. Mixer efficiency tests had been performed. Two sizes of uncrushed gravel material were used. Slump was maintained at 1 to 1-1/2 in., and entrained air at 4 to 5 percent. Recorders were used and conventional procedures for batching and weighing were followed. Concrete was hauled to the site and deposited in front of the paver in end-dump trucks (Figure 22). The operation of the trucks on the prepared surface of the base did not appear to cause any distress (shear failure or densification) in the material.

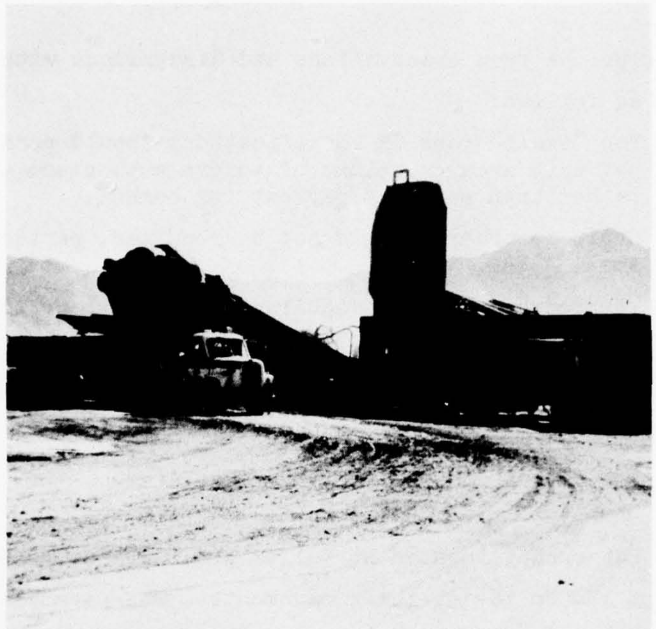


Figure 21. Rex central mix plant

Figure 22. End-dump trucks depositing concrete in front of the paver

51. The pavement was formed with a Blaw-Knox form paver (Figures 23 and 24). The essential elements of the paver were spud vibrators for consolidating the concrete and a forming plate for shaping the surface of the material between the fixed side forms. The forms were conventional paving forms. Steel reinforcing bars were welded to the back of the forms and the dowels tied to the bars to prevent movement during concrete placement (Figure 25). A string line was established to check and maintain alignment of the dowel bars.

52. The surface of the pavement was finished with a Gamaco finisher (Figures 26 and 27), having essentially two counterrotating auger-rollers that moved transversely across the pavement. Hand finishers floated the surface, corrected low and high spots, and finished the edges. Texture was applied with a burlap drag and curing compound sprayed to cover the exposed surfaces (Figure 28). Inspection of the surface finish was extensive. Frequent checks (longitudinal and transverse) of the surface smoothness were made with 12-ft straightedges to delineate low or high areas for correction by the finishers (Figure 29). Particularly close attention was given the area adjacent to headers (Figure 30).

53. Contraction joints were sawed. On a taxiway that had just been completed, and at the beginning of this job, Unitube inserts were used to form the weakened plane. This was discontinued and sawing of the weakened plane initiated. The contractor was able to saw the weakened planes without random cracking occurring. Beams were cast and tested using conventional (as specified in MCGS 02611[3] and TM 5-822-7[4]) procedures. Form removal was accomplished after the dowels were removed. This is contrary to procedures specified in MCGS 02611[3] but apparently caused no serious problems. Specified procedures are that the dowels be bonded in place and that the unbonded (greased) end be in the fill-in lane.

54. Checks of the surface with a 12-ft straightedge revealed that the longitudinal smoothness was very good with few apparent high or low areas. The transverse measurements consistently indicated a low area

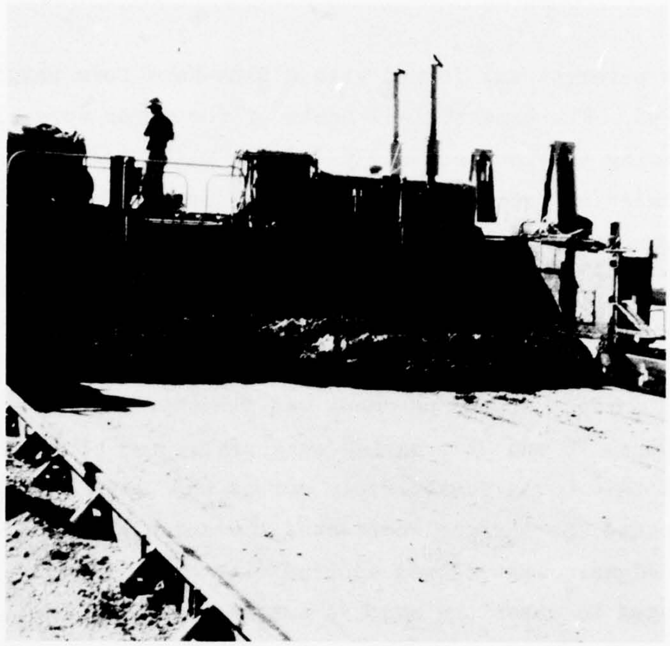


Figure 23. Front view of Blaw-Knox paver

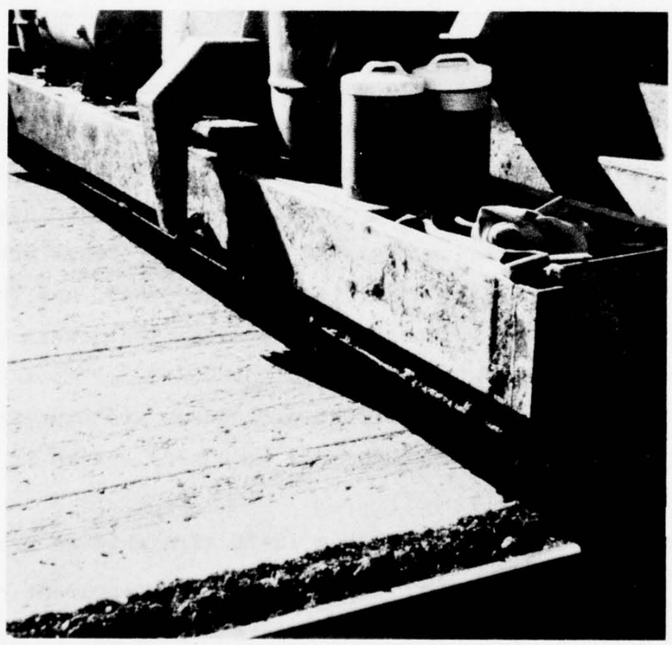


Figure 24. Concrete as formed by paver

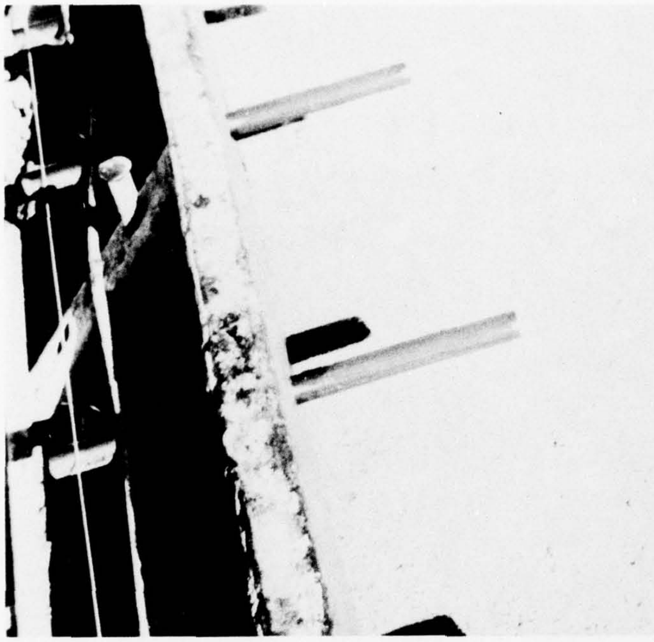


Figure 25. Dowels fixed to side forms

Figure 26. Gamaco finisher in operation

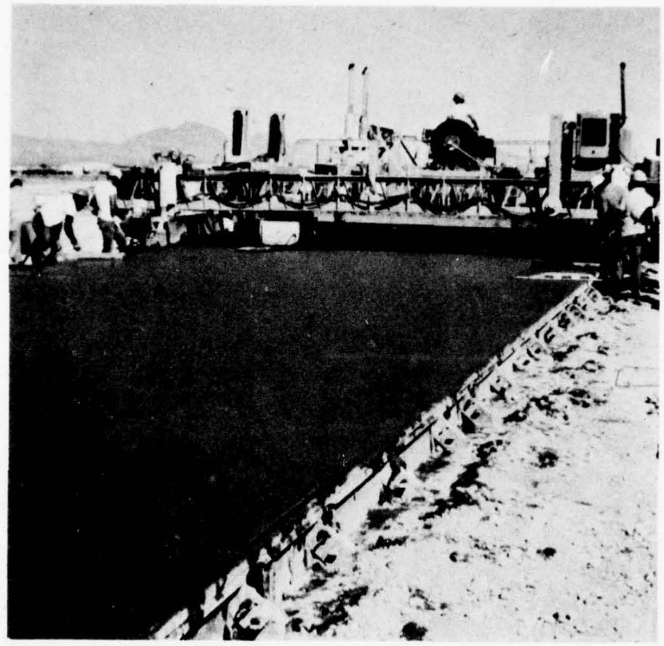


Figure 27. Surface as finished by Gamaco finisher

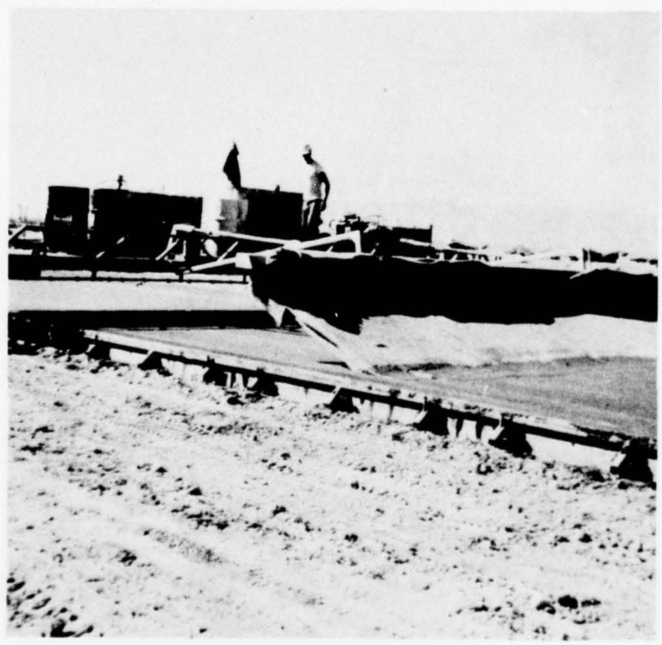


Figure 28. Texturing of pavement surface with a burlap drag

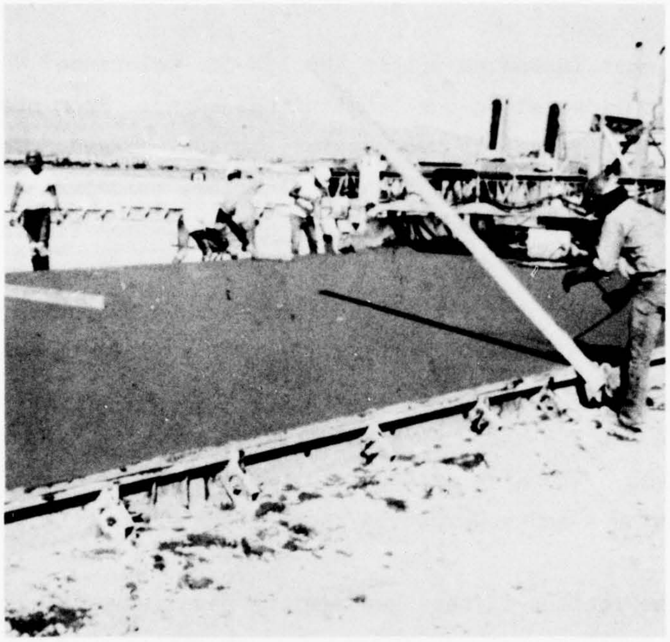


Figure 29. Check of transverse smoothness

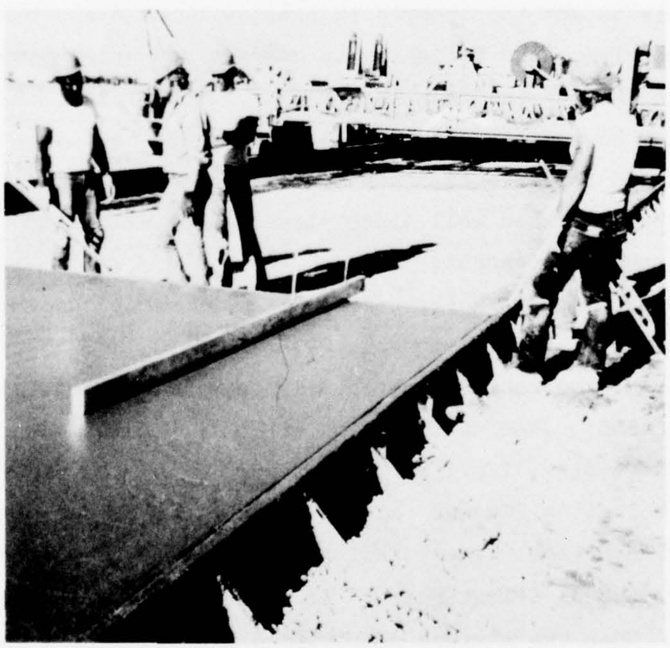


Figure 30. Check of smoothness near header

(although in most instances within the 1/4-in. tolerance) 4 or 5 ft from the edge (or a ridge along the longitudinal edge). From observations of the finishing operations two possible causes emerged. The apparent low area may have been caused by hand finishers building up the area adjacent to the forms or by the rollers on the Gamaco finisher, which did not completely move across and off the pavement but stopped along the edge. The tendency for the hand finishers to overbuild along the edges has also been observed on slip-form jobs. This is the area that is readily accessible to the finishers and they want to produce a square corner. As a result, there is a tendency to overwork and overbuild along the edges. The area adjacent to two transverse construction joints was checked and as expected these areas showed the poorest smoothness.

55. Observations of the sawed joints revealed only minimal raveling and spalling and no uncontrolled cracking. The joints formed with the Unitube on the taxiway were observed. There was some evidence of spalling and handwork around the inserts (Figures 31 and 32). It was impossible to get the inserts in place without disturbing the surface which requires hand finishing to correct and which results in unevenness in the surface near the inserts. The project engineer indicated that he preferred sawing because of the necessity for hand finishing around the inserts. The system used for stabilizing the dowels apparently worked well since visual observations of the dowels indicated adequate alignment.

56. There had apparently been some controversy concerning the payment for the cement. In paragraphs 24.2 and 24.3, MCGS 02611,[3] it states that the "theoretical" batch weights will be used in computing payment for cement. The difficulties or controversies are apparently a matter of semantics, i.e., actual and specified. On WES Form 553 the terms "Theoretical Cement Factor" and "Actual Cement Factor" are used. The "Theoretical Cement Factor" is based on the desired air content and the "Actual Cement Factor" is based on the air content of the trial batch. When the mixture proportions are specified, they are based on the desired air content (although this may vary from batch to batch,

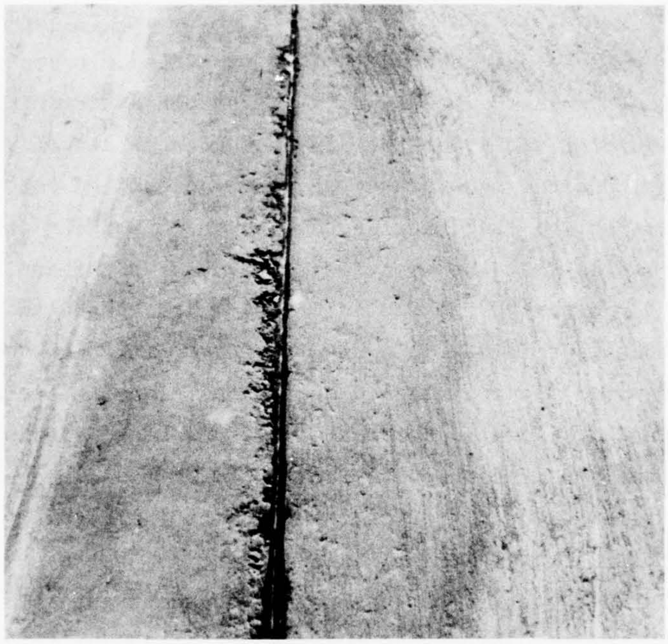


Figure 31. Spalling adjacent to Unitube inserts

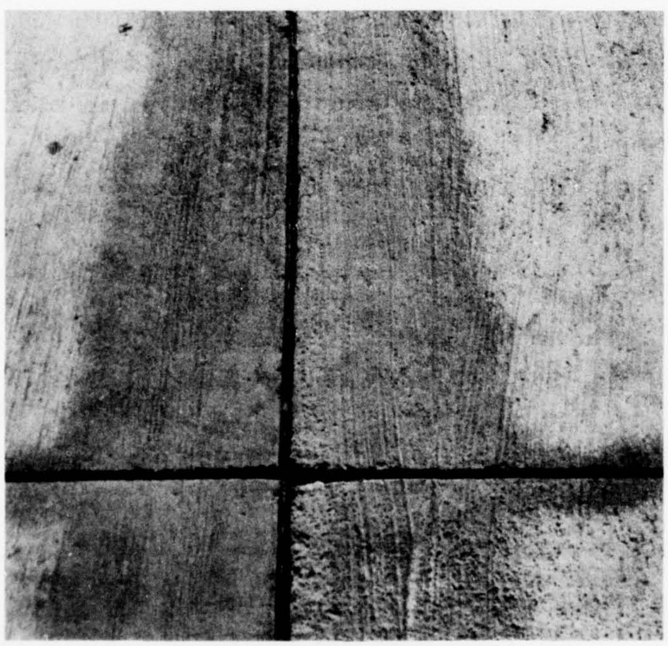


Figure 32. Evidence of hand finishing adjacent to inserts

the average should be near the desired or specified air content) and the "Theoretical Cement Factor" should be used in determining batch weights. Because of variations in air content, the actual yield of each batch may vary, but the same amount of cement should go into each batch. The air content should fluctuate around the specified air content so that the average is near the specified. The paragraphs are correct as written, but for clarity "theoretical" should be changed to "specified" with a note that "specified" is equivalent to "theoretical" on WES Form 553. The word "actual" should be avoided since this could create a situation where the contractor could take advantage of the situation and increase the cement content to above that which is necessary and expect to be paid based on the amount of cement indicated by the recorders. This aspect of control also points out the need for some form of statistical control of the amount of cement actually used in each batch, if the present system for payment of cement is going to be continued (in lieu of making mix design and strength attainment a contractor responsibility). If such controls were available, the actual amount of cement could be determined from the recorders and payment made based on this amount of cement. This would then permit the word "actual" to be used in the specifications and would minimize misunderstandings.

57. A general discussion concerning construction of concrete pavements was held with personnel at the job site and below are some comments on these discussions:

- a. Bids should specify whether the contractor proposes to use a slip-form paver or forms.
- b. More quality control is needed for slip-form jobs; i.e., more CE inspectors.
- c. For slip-form jobs, sawing of transverse contraction joints should be specified.
- d. Special mix-design procedures should be established for selecting mixture proportions for slip-form jobs.
- e. Contractor requirements should be established for "larger" paving jobs. This might take the form of specified rates of placements to eliminate smaller contractors or requirements that the prime contractors do a certain portion of the work with their own personnel to eliminate jobbers.

Scott AFB, Illinois (PFC Construction), May 1976

58. A visit was made on 17 May 1976 to Scott AFB to observe construction of a PFC surfacing on the main runway. Prior to this visit of the actual construction site, WES participation in this project had been limited to comments and suggestions on materials to the Omaha District of the Missouri River Division, Army Corps of Engineers. Inspection of construction, the contractors' quality control program, and the CE quality assurance program provided the data contained in this report.

Materials

59. Aggregate. A 5/8-in.-maximum-aggregate-size gradation was selected for this project, and six materials were blended to meet the specifications. Two felsite porphyry coarse aggregates were blended with one felsite porphyry manufactured sand and one natural sand along with two mineral fillers; one mineral filler was a limestone dust and the other a hydrated lime. Stockpile gradations and percentages of each material recommended are shown in Table 4. Table 5 shows the stockpile gradations after the two sands and two fillers were blended. This blending was necessary due to limitations on the number of cold feeds. The manufactured sand and natural sand were blended in the stockpile prior to placement in a cold bin. The limestone dust and hydrated lime were blended as they were added to the same silo. The job-mix formula, specification limits, design binder content, and mix temperature are shown in Table 6.

60. Asphalt. An SS-1h emulsion was used for the bituminous tack coat. The binder used for this PFC was a neoprene-modified asphalt consisting of an 85-100 penetration asphalt and 1.5 percent neoprene rubber additive. This material was blended by Husky Oil in Cody, Wyoming, and shipped to the job.

Specifications

61. In preparation of specifications for this PFC job, the Omaha District elected to modify CE-807.22, "Military Construction Guide Specifications,"[6] for use to contract for the PFC pavement. This is in

lieu of adopting other agency specifications for PFC; for example, the FAA Item P-402, "Porous Friction Surface Course."[7] There are several items in this modified specification that warrant some discussion regarding suitability in both this application and in future PFC jobs that may be done by the CE.

62. Section 3.2, "Fine Aggregate." The natural sand is limited to 10 percent. There does not seem to be any experience indicating the suitability of natural sand or the appropriateness of limiting the material to 10 percent. However, in an open-graded mix such as a PFC where there is minimal aggregate interlock, it is suggested that it might be best to exclude the use of natural sand altogether.

63. Section 3.3, "Mineral Filler." 1.5 percent hydrated lime was required and, if necessary to meet gradation requirements, natural mineral filler would be removed to provide for addition of the hydrated lime. There are no experimental data to justify this requirement for PFC. The use of 1.5 percent hydrated lime has apparently crept into PFC specifications from its frequent use. Whether to use hydrated lime or not should be based on the same engineering judgment used in evaluating stripping tendencies of job aggregate for dense graded mixtures. On that basis, hydrated lime would be added when an antistripping agent is required to compensate for any stripping tendencies of the aggregate. Where the hydrated lime would result in excess minus No. 200 material a commercial antistripping agent could be specified.

64. Section 3.4, "Bulk Impregnated Specific Gravity." This is the only specific gravity method referred to in the job specifications, and it seems that it may be an inappropriate requirement for the job aggregate.

65. Section 4.1, "Asphalt Cement." The modified asphalt cement specifications used in this job specification were adopted from specifications recommended by Husky Oil. These specifications seemed to be appropriate and have worked well for both this job and past jobs that the same specifications have been used for.

66. Section 5, "Aggregate Gradation." The aggregate gradation shown in the job specification was recommended based on earlier research

by WES; however, subsequent developments indicated that the following gradation would result in better permeability of the PFC pavement surfacing. Specifically, the permeability is greatly affected by the percent passing the No. 8 sieve.

Sieve Size	Cumulative Percent by Weight Passing
5/8 in.	100
1/2 in.	85-95
3/8 in.	70-85
No. 4	25-40
No. 8	12-20
No. 200	3-5

67. Section 15.6, "Handspreading in Lieu of Machine Spreading." Current experience in paving operations indicates that the requirement stating rakers wear stilt sandals is an antiquated requirement and should be eliminated from specifications.

68. Section 16, "Compaction of Mixture." Compaction requirements for PFC's are neither stringent nor complicated; however, the discussion of the compaction pattern and technique is excessive in this specification. Experience has indicated that compaction and workability qualities of PFC have good tolerance to construction practices. A simple requirement of two to four passes of a steel-wheeled roller seems to be adequate.

69. Section 16.3, "Rolling with Pneumatic-Tired Roller." There was a requirement to roll the PFC with a rubber-tired roller to remove the sheen of the freshly laid PFC pavement. There is no indication that the sheen of the freshly laid PFC will have any effect on either the short- or long-term performance of the PFC. The sheen will disappear in a few days after the asphalt is dulled through exposure to sun, dust, and traffic. There seems to be more harm in rolling with a rubber-tired roller because the hot PFC is picked up by the roller tires. This was verified by cessation of the pneumatic rolling of the PFC.

70. Section 21, "Sampling of Pavements." In this section, it is inferred that there are a number of tests that can be run to indicate quality and performance characteristics of the PFC. Mix gradation is about the only quality control test that can be run with confidence.

It is difficult to determine binder content due to the excessive binder that is in the mix. Mix samples that are taken will lose a substantial amount of asphalt both on sampling tools and in transport containers, and in subsequent handling for test preparation. Past experience indicates a wide variation in the binder content that would be determined with normal extraction procedures. In-place density determinations would have to be made through coring or sawing of samples and separation of the PFC surface course from the underlying pavement layers. Separation should be done with a saw. The PFC density could be determined by weighing the sample in air and calculating the volume from the physical geometry of the sample. The only other test that might be conducted would be a field water permeability test using the WES falling-head permeability device.

Construction observations

71. As mentioned previously, the cold feed facilities at the asphalt plant located on a taxiway adjacent to the construction site, were limited; consisting of three bins and one silo. Two of the cold bins were used for the 5/8- to 1/2-in. size aggregate and the minus 5/8-in. aggregate, respectively. The third cold bin was used for the blended manufactured and natural sands. The silo was used to feed the blended limestone dust and hydrated lime. There seemed to be a lack of information concerning calibration of the cold feeds, but this procedure was not observed because construction was already in progress when the site was visited. The asphalt plant screening unit had 5/8- and 1/8-in. screens. There was poor balance between the cold feeds and material being pulled from the hot bins as is depicted in Figure 33 by the overflow from the asphalt plant hot bins.

72. Initially, the SS-1h emulsion tack was applied at a rate of 0.03 to 0.04 gal/sq yd, and then rolled with a rubber-tired roller. The roller tires picked up the tack material and dropped it as the buildup continued. These patches bubbled up through the PFC. The contractor was directed to remove the patches with shovels, which required a lot of effort. The tack coat seemed to be light and it was suggested that

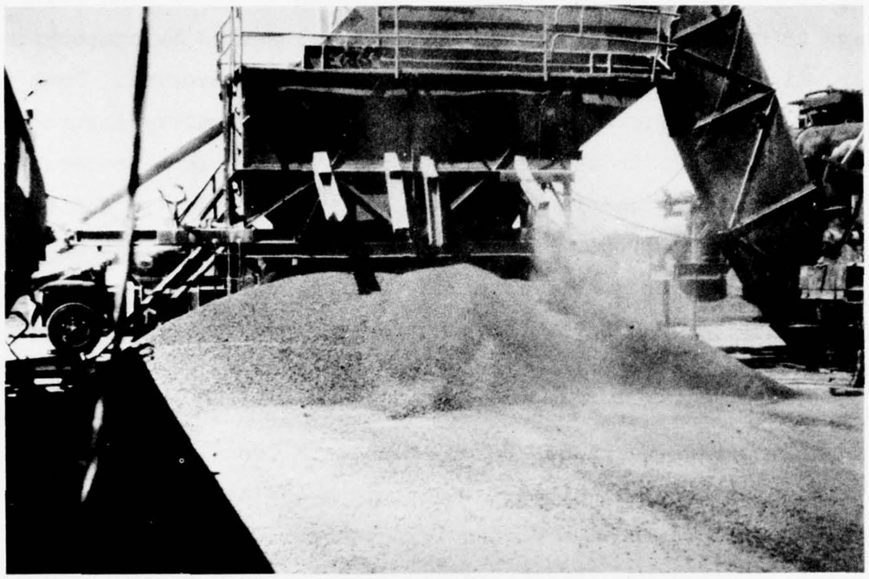


Figure 33. Hot-bin overflow

the rate of application be increased to about 0.05 gal/sq yd. This with proper selection of dilution rate and temperature of the emulsion should result in an adequate, uniform coverage of the pavement surface by the tack coat and would make rolling unnecessary.

73. Production of the PFC mix was started with a mix temperature of 285° F, and this temperature was being used at the time the site was visited. Due to an apparent lack of drainage to the underlying pavement surface it was suggested that the temperature be increased to 300° F. Additionally, if this temperature was not detrimental to the mix, then the binder content could be increased by 0.2 percent from the 6.5 percent binder content that was being used at the start of the job. These suggestions were followed but did not seem to result in the desired additional drainage. Omaha District personnel felt that the mix looked better when produced at the 6.5 percent binder content at 300° F, and these mix production conditions were maintained through the rest of the job. There was little drainage observed in the transport

trucks, in the laydown machines, or in place. It was suggested that rolling be delayed a few minutes after laydown to allow some asphalt drainage to take place before the pavement was sealed by compaction. However, little additional interface drainage was observed. Both a contractor's quality control and the government's quality assurance program were applied to this construction. Table 7 shows recorded quality control data and Table 8 shows extracted gradation and binder content determined by the MRD Laboratory. A noteworthy fact might be that although the job quality control data showed little variation in binder content the MRD Laboratory data do reflect variation. The PFC mix had good workability in spite of apprehension by district personnel on this point. The mix had good tolerance to laydown operations and to handworking that was required on occasion. Good longitudinal construction joints were obtained. A different surface texture resulted where a hydraulic extension to the laydown machine was used to expand the paving lane width. This hydraulic extension did not have an extension to the screed, and the difference in surface texture was apparent. Subsequent rolling did not eliminate the difference in appearance. Adequate compaction seemed to be applied by the steel-wheeled roller which routinely made two to four passes on the pavement. The rubber-tired roller that was used to remove the sheen from the PFC surface was discontinued because of pickup of the mix. Figure 34 shows a general view of the PFC pavement.

Miscellaneous observations

74. At cross taxiways, a 1/2-in. notch was cut into the pavement so that the PFC would butt into a vertical face. This requirement seemed to be redundant, resulting in extra work. Past experience indicates that satisfactory performance can be expected if the PFC edge is left free. Initial, after-construction raveling will occur until the free edge ravels to an angle of repose, and then raveling will stabilize. MRD personnel felt that the screed operator on the laydown machine over-compensated for the thickness of pavement, resulting in a variation in thickness. It was suggested that future PFC jobs require that a full-time laydown inspector be supplied either by the government or by the

Figure 34. General view of PFC pavement

contractor to ensure that proper screed height is maintained. This job also emphasizes that the minimum thickness allowed be not less than the maximum aggregate size.

Scott AFB, Illinois (PCC Pavement Construction), September 1976

75. The PCC constructed was for 1000-ft extensions on both ends of runway 13-31 at Scott AFB, Illinois. Three-hundred-foot sections on both ends are 150 ft wide and the remaining 700 ft of each extension are 75 ft wide. The 75-ft-wide portions are composed of three 25-ft-wide lanes with a uniform thickness of 19 in. The outer 37-1/2 ft on either side of the 75-ft-wide sections is flexible pavement. The 150-ft-wide portions are composed of five 25-ft-wide lanes and two 12-1/2-ft-wide lanes. This pavement is 18 in. thick with the outer edges and ends of these sections thickened to 24 in. All longitudinal construction joints are doweled and the transverse contraction joints were sawed at 25-ft intervals.

76. The underlying material was a 4-in.-thick filter course composed of three parts slag and two parts natural sand. Maximum particle size was approximately 3/8 in. After mixing, the material was spread, compacted, rough-cut about 1/4-in. high with a motor grader automatically controlled from a string line, the forms set and the surface trimmed with a subgrade planer operating on the forms (Figure 35). The surface was moistened, rolled with a steel-wheeled roller, and then moistened again just prior to concrete placement. Beneath this filter course was a lean clay (CL) fill material which varied in depth from 1 to 6 ft. The natural subgrade was classified as a heavy clay (CH) material.

77. The forms used were new and had several interesting features. Special brackets had been welded to the braces for positioning and securing the dowels. Rubber grommets were used in oversized holes in the forms to secure the dowels. This innovation for the dowels was designed for ease and accuracy in installation, ease in form removal, and stability of the dowels during concrete placement. According to personnel, it worked extremely well (Figures 36 through 40). It was also noted that the forms were extended some 70 ft beyond where the pavement began or ended in order to allow equipment to be set up and ready to go, or after finishing enable the equipment to get clear of the fresh concrete so no delay would be encountered.

78. Concrete was batched and mixed in a 9-cu-yd Ross central mix plant. Automatic recording equipment was used. Coarse aggregate consisted of two sizes (1-1/2- and 3/4-in. maximum size) of crushed limestone. Fine aggregate consisted of two sizes of natural sand. This was somewhat unusual, but the sand that comprised the major portion was lacking in fines and did not meet CE specifications. To remedy this, 200 lb/cu yd of very fine natural sand was added. Type I cement was used at a rate of 520 lb/cu yd. The resulting mix had a slump of about 2 in. and an air content of 5.5 ± 1.5 percent. The specified strength was 630 psi at 14 days and CE personnel indicated that this was being met.

79. Concrete was hauled to the paving site in end-dump and agitator trucks with chutes. The end-dump trucks deposited the concrete into a

Figure 35. Subgrade planer trimming the filter course

Figure 36. Driving pins to secure side forms

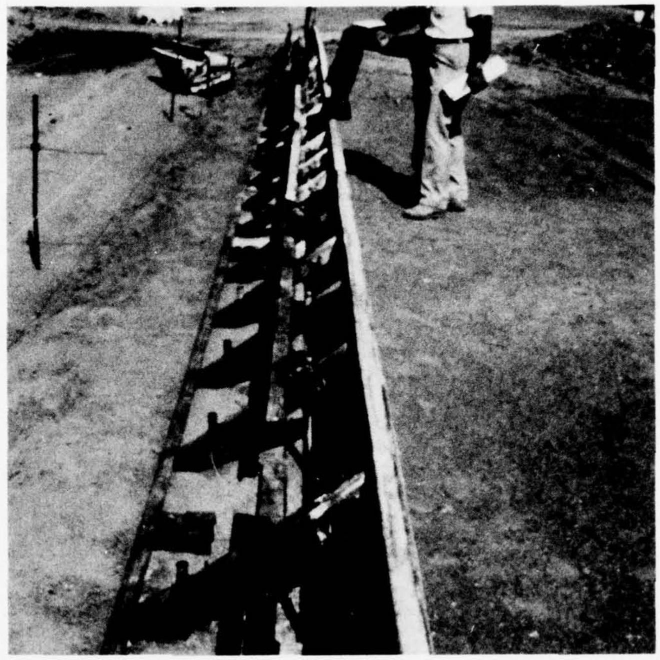


Figure 37. Side forms in place (dowels not inserted)

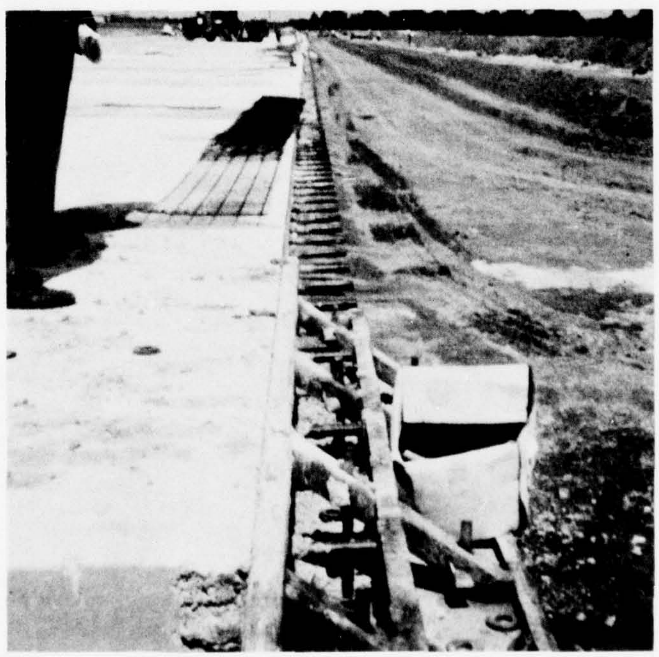


Figure 38. Edge of finished pavement

Figure 39. Removal of forms

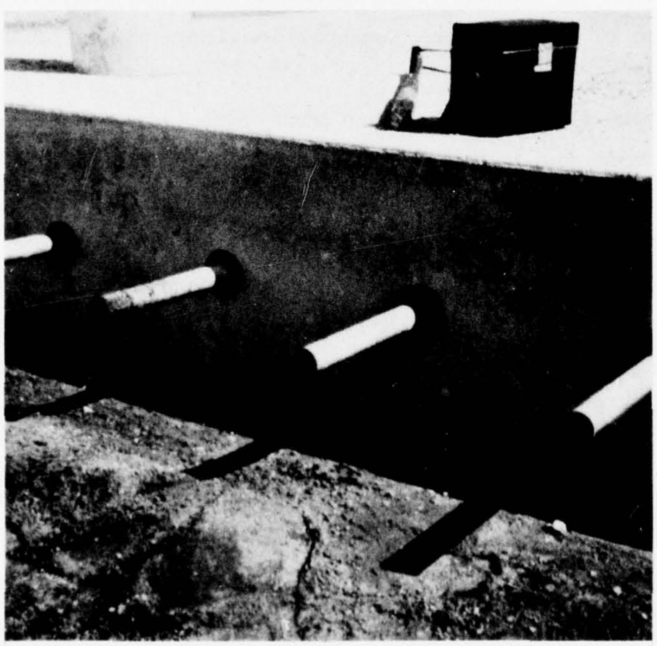


Figure 40. Completed longitudinal construction joint (rubber grommets still in place)

Rex belt spreader which spread the concrete across the center portion of the paving lane. The agitator trucks with the chutes deposited concrete along the edges of the paving lane. It was unclear why the Rex spreader was not used to spread the concrete for the entire paving lane width, but apparently it was not capable of spreading the concrete for the full 25-ft width. This procedure for spreading was within specification requirements and was probably not detrimental to the quality of pavement obtained, but the use of the agitator trucks only complicated what should have been a simple process. The Rex spreader was followed by what was referred to as a "butterfly" spreader. This was a spreader with a paddle which moved transversely across the paving lane and spread the concrete to a uniform thickness. The paver was a Heltzel machine with spud vibrators and two transversely oscillating screeds (Figure 41). The paver was followed by a Heltzel pan float and finally by hand finishers. The paving equipment was old and appeared to be in a rather poor state of repair, but apparently was doing an adequate job. The surface and edges of the pavement appeared to be satisfactory, and there was no evidence of inadequate consolidation (honeycombs or unusually numerous voids).

80. Texture was applied with a wire comb (Figures 42 and 43). Initially the comb was mounted on a CMI cure-texture machine, but this procedure was abandoned after a short time and the texture applied manually. Curing compound was applied with the CMI machine.

81. No joint construction problems were noted or mentioned by CE personnel. The alignment of longitudinal joints and dowels in these joints appeared to be adequate. Transverse contraction joints were dry sawed with abrasive blades. The groove was 1/4 in. wide and 4-3/4 in. deep. No uncontrolled cracking had been experienced. After sawing, the grooves were blown out with compressed air, flushed with water, blown dry with compressed air, sealed with masking tape, and covered with wet sand (Figure 44). Details of the special joint between the old and new PCC pavement were as recommended in TM 5-824-3.[8] No particular problems were observed or mentioned by CE personnel.

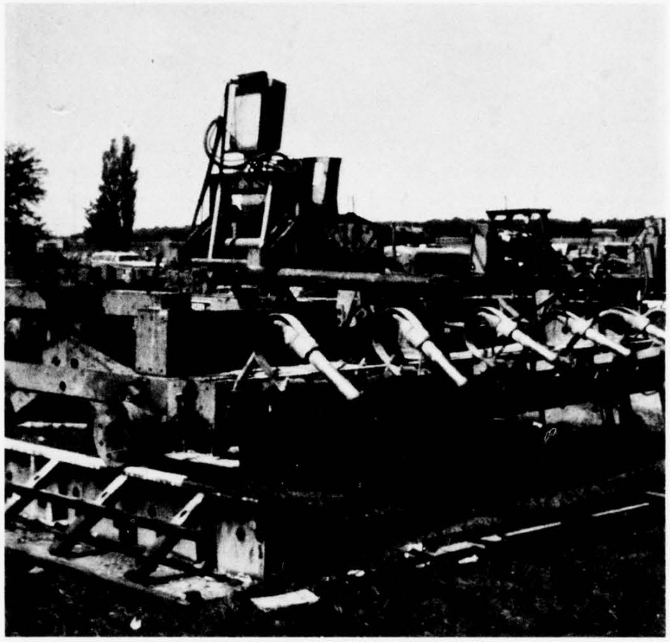


Figure 41. Heltzel paver

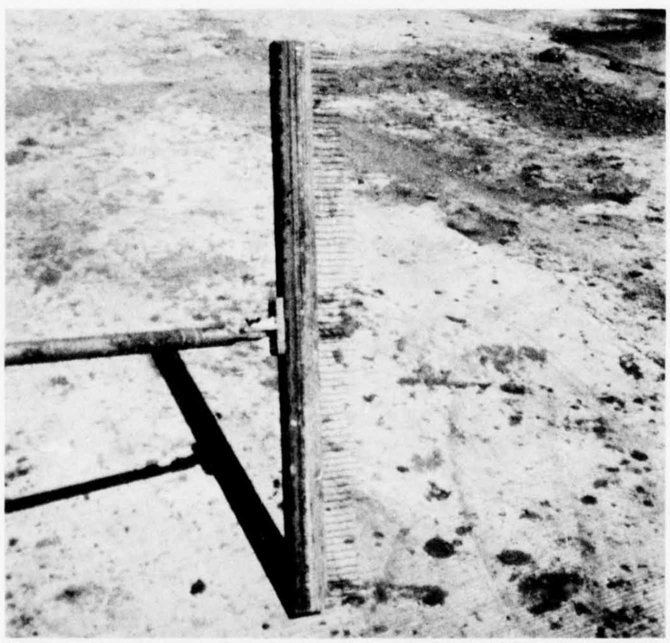


Figure 42. Wire comb for application
of surface texture

Figure 43. Wire comb surface texture

Figure 44. Sawed groove for transverse contraction joint

82. Longitudinal smoothness was, as best as could be determined on the wire-tine-textured surface, adequate. Once again, the problem of measuring small deviations ($\approx$1/8 in.) of the surface with a straightedge were encountered because of the rough surface texture. Transverse smoothness was no problem. There was no measurable tendency for the edges to slump nor was there evidence that the edges had been overworked or built up too much as had been the case on several jobs observed previously. Straightedge measurements along the edge revealed that low or high spots encountered were small and were probably the result of floats, trowels, or edging tools. As on other jobs, the worst surface was in locations where handwork was extensive, such as adjacent to headers.

83. A general discussion was held with CE personnel at this job site concerning construction procedures. Below are conclusions from these discussions and from observations of the job:

a. Contractual problems between the prime contractor and the subcontractor caused some problems. The situation was one in which the prime contractor had little expertise in airport pavement work. In addition, the prime contractor's personnel were doing only a limited amount of the work. The subcontractor for the paving was a large paving contractor who apparently paid little attention to the prime contractor. This type of situation does create problems and some requirements are needed to ensure that prime contractors do certain portions of the work and not act simply as a jobber.

b. The contract was being run with the contractor providing the quality control. This situation coupled with the contractual problem discussed in the preceding paragraph created a situation that was not desirable to CE personnel. They did not know exactly what their role was: guidance, control, or merely acceptance or rejection of the finished product.

c. Another problem encountered at this site was the texturing of the concrete using the wire comb. Job specifications called for 3/16-in.-deep serrations. CE personnel indicated that when they tried to get more penetration aggregate would be dislodged. It was also indicated that with the wire comb texture it was impossible to coat the inside of the serrations with curing compound. This did not appear to be a major problem, but the amount of area to cover is increased when textured, and a study should be

conducted to determine what rate of application should be used for different types of texture (burlap drag, wire comb, brush, or grooved). It may be that the specified 400 sq ft/gal rate for each coat in a two-coat operation needs to be changed.

d. It was pointed out that paragraph 11.4.1 in the section on transportation equipment in MCGS 02611[3] is not well written. The first sentence should be removed and replaced with a sentence indicating that haul equipment will be approved by the contracting officer. In addition, guidance for the contracting officer should be provided in the standard practice manual (TM 5-822-7).[4] This should include permissible ranges of temperature, haul distance, concrete slump, time and discharge requirements for the various types of haul units such as nonagitating equipment, truck agitators, or truck mixers.

e. Prior to construction there were discussions on the operation of slip-form pavers on the filter course. The impression of WES personnel after observing the material in place was that slip-form pavers probably could have been operated. There might have been times when the tracks on the paver would have spun and displaced the material, but this would have been no major problem. The material in these areas would have had to have been recompacted and graded before concrete could have been placed because of the disturbance from normal construction traffic. If the contractor had really wanted to use a slip-form, the filter course could have been placed one lane at a time and the paver operated on the subgrade as necessary. However, no matter what the reasons for selecting the forms, it was probably a wise move because of the thickness of the concrete, dowels in the longitudinal joints, and short lengths of paving lanes. All of these cause problems for slip-form pavers.

PART III: CONCLUSIONS AND RECOMMENDATIONS

84. The following conclusions and recommendations are based on observations of the construction procedures employed, the finished pavement, and discussions with CE personnel at the projects visited. Many of the conclusions are merely identification of trouble areas which need revisions, and many of the recommendations are that more detailed studies be made in order to provide data for specific revisions to the guide specifications and standard practices manual.

85. An overall evaluation of the PFC constructed at Scott AFB indicates a satisfactory construction project. There seemed to be some conflict between the contractor's quality control and certainty about components that go into the mix which are important in the successful production of a bituminous mixture. The mix design procedure outlined by WES and applied by MRD personnel appears to be adequate. The recommendations on construction techniques and processes in the field indicate that there is some tolerance or latitude in both the mix design procedure and the PFC surfacing itself.

86. In MCGS 02611[3] the word "theoretical," modifying batch weight, is used to describe procedures for determining the amount of cement for payment. This should be changed to "specified," and a note should be added that "specified batch weights" are equivalent to "theoretical batch weights" on WES Form 553 where mix design calculations are made.

87. In MCGS 02611,[3] the paragraph outlining requirements for transportation equipment for completely or partially mixed concrete has caused some confusion for field engineers. The transportation equipment should conform to CRD-C 31,[5] but the exact type selected should depend on the particular requirements of each project. The contracting officer should approve the equipment to be used for transporting concrete mixed partially or completely in a stationary mixer from the mixer to the point of placement. The equipment should be capable of transporting the concrete from the mixer to the paving site without segregation or initial set occurring and should be capable of

discharging the concrete without segregation. The approval of transportation equipment should be based on its ability to deliver the concrete as specified under the particular project conditions; i.e., temperature, haul distance, concrete slump, and discharge requirements.

88. CE is the only major specifying agency which currently requires recorders on batching equipment. This means that certain contractors do not have recording equipment available but must obtain it solely for CE jobs. The elimination of requirements for strip recorders is recommended, particularly for projects involving vehicular roads and streets, fixed wing ramp and apron facilities, and heliport pavements where the volume of concrete is 5000 cu yd or more. This recommendation will be pertinent to a subsequent recommendation that cement be a separate pay item.

89. There is a tendency for finishers to overwork the edges of paving lanes. This is particularly true when the finishers try to compensate for any edge slumping which may have occurred in the edges of slip-formed lanes. This has led to overcompensation (building ridges along longitudinal construction joints) for edge slump and nondurable surfaces. Paragraphs in TM 5-822-7[4] dealing with finishing should be revised to caution against permitting overbuilding the edges and against permitting late finishing; i.e., finishing after initial set has begun.

90. The placement of dowels in longitudinal construction joints with a slip-form paver at Fort Eustis, Virginia, was a unique practice. The apparent success of the procedures employed certainly enhances the attractiveness of using slip-form pavers where dowels are required in longitudinal joints. The procedures for installing dowels in longitudinal joints at Nellis AFB, Nevada, were different from those in CE specifications. From a construction standpoint the procedures used at Fort Eustis and at Nellis AFB were apparently satisfactory. However, the performance of the longitudinal joints must be evaluated before the procedures can be accepted. Therefore, it is recommended that the performance of the longitudinal joints at these installations be periodically evaluated to assess the acceptability of the construction

procedures used. Evaluation should be based on the ability of the joints to distribute load, ability of the joints to accommodate movement of the slabs, and the absence of distress (spalling or cracking) along the joints which could be attributed to misalignment or improper location of the dowels.

91. There is a trend toward specification of more aggressive textures on pavements where aircraft and vehicles are to operate at high speeds. Two popular textures are those applied with a brush or broom and those applied with a wire comb. Our present specifications for these types of texture are unsatisfactory. More definitive specifications are needed for test procedures (sand or putty patch method) that determine average texture depth.

92. For more aggressive surface textures such as broom or wire tine texture, the surface area that needs coating with curing compound is larger than the area with a burlap drag texture. Therefore, the needed rate of application of liquid curing compounds may be different for various types of texture. A study should be made to determine if the specified application rate of 400 sq ft/gal for a two-coat operation is acceptable for the range of surface textures currently being used.

93. Another needed change in the specifications which is a result of the aggressive textures being used is the surface smoothness tolerance, and in particular the longitudinal requirement. With a straightedge it is impossible to detect deviations of the surface as small as 1/8 in. Recognizing that the 1/8-in. requirement is not necessary for adequate riding quality, that it is a lower limit requirement based on the ability of equipment to form the surface, and that the purpose of the requirement is essentially to ensure the overall quality of the workmanship; it is recommended that a more realistic surface smoothness tolerance be adopted or that equipment be developed capable of detecting surface deviations as small as 1/8 in.

94. It is recommended that consideration be given to instituting procedures whereby the contractor is responsible for selecting a mix design from approved materials and payment is made on the basis of units of concrete (cubic yards or square feet) in place. This will

require detailed specifications and testing procedures for concrete strength and entrained air content which include minimum and maximum values and maximum variability. This will eliminate the need for cement as a separate pay item, the need for recorders, and will permit the contractor more freedom to vary mix design. Such procedures will hopefully result in lower cost pavements by stimulating competition among contractors.

95. Consideration should be given to instituting procedures which will require the prime contractor to do a specified portion of the work with his own work forces. This will eliminate jobbers and will make the contractor more responsive to the contracting officer.

96. It is recommended that a project such as the one described in this report be conducted annually, then used to make appropriate changes in the guide specifications and standard practices manual.

REFERENCES

1. White, T. D., "Porous Friction Surface Course," Miscellaneous Paper No. S-75-12, Feb 1975, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

2. __________, "Field Performance of Porous Friction Surface Course," Miscellaneous Paper No. S-76-13, Apr 1976, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

3. Departments of the Army, Navy, and Air Force, "Military Construction Guide Specifications - Concrete Pavement for Roads and Airfields," MCGS 02611, Dec 1975, Washington, D. C.

4. Departments of the Army and Air Force, "Standard Practice for Concrete Pavements," Technical Manual TM 5-822-7 and Air Force Manual AFM 88-6, Chapter 6, Sep 1975, Washington, D. C.

5. U. S. Army Engineer Waterways Experiment Station, CE, Handbook for Concrete and Cement, CRD-C 31 - Vol 1, Aug 1949 (with quarterly supplements), Vicksburg, Miss.

6. Department of the Army, "Military Construction Guide Specifications - Bituminous Intermediate and Surface Courses for Airfields, Heliports, and Tank Roads (Central-Plant Hot-Mix)," CE-807.22, Dec 1972, Washington, D. C.

7. Department of Transportation, Federal Aviation Administration, "Standards for Specifying Construction of Airports," Advisory Circular No. 150/5370-10, Oct 1974, Washington, D. C.

8. Departments of the Army and Air Force, "Rigid Pavements for Airfields Other Than Army," Technical Manual TM 5-824-3 and Air Force Manual AFM 88-6, Chapter 3, Jan 1970, Washington, D. C.

Table 1

Rebound Hammer Tests
Space Shuttle Landing Facility
Station 1+84

	Rebound Reading and Compressive Strength,* psi			
Lane No.	West Edge	Third Point	Third Point	East Edge
1	24P 2400	28 3200	28 3200	27P 2950
2	20P 1800	28 3200	28 3200	20P 1800
3	20P 1800	28 3200	27 2950	23P 2250
4	23P 2250	23 2250	25 2600	26 2800
5	24P 2400	27 2950	24 2400	20P 1800
6	27P 2950	26 2800	26 2800	28 3200
7	23 2250	35 4600	21P 1900	23P 2250
8	22P 2100	35 4600	26P 2800	23P 2250
9	21 1900	23P 2250	23 2250	24P 2400
10	24P 2400	26 2800	23P 2250	20P 1800
11	20P 1800	20 1800	25P 2600	21P 1900
12	32 3900	29P 3350	30 3500	22P 2100
Mean	23.33 2300	27.33 2666	25.50 2700	23.08 2262
Rebound Std Deviation	3.45	4.44	2.54	2.75

Note: "P" readings located on oil-based traffic paint.
* Strengths obtained from correlation with rebound number.

Table 2

Rebound Hammer Tests
Space Shuttle Landing Facility
Station 101+79

Lane No.	Rebound Reading and Compressive Strength,* psi: West Edge	Third Point	Third Point	East Edge
1	22P	25	30	30
	2100	2600	3500	3500
2	25	25	26	20
	2600	2600	2800	1800
3	24	22	22	24
	2400	2100	2100	2400
4	18	28	36	27
	<1800	3200	4750	2950
5	16	34	25	31
	<1800	4300	2600	3750
6	30	31	25	21
	3500	3750	2600	1900
7	28	26	20	22
	3200	2800	1800	2100
8	22	30	24	28
	2100	3500	2400	3200
9	25	28	30	22
	2600	3200	3500	2100
10	25	28	30	22
	2600	3200	3500	2100
11	20	24	24	24
	1800	2400	2400	2400
12	30	22	25	30
	3500	2100	2600	3500
Mean	23.75	26.92	26.42	25.08
	2362	2938	2863	2616
Rebound Std Deviation	4.41	3.63	4.36	3.92

Note: "P" readings based on oil-based traffic paint.
* Strengths obtained from correlation with rebound number.

Table 3

Rebound Hammer Tests
Space Shuttle Landing Facility
Station 109+90

	Rebound Reading and Compressive Strength,* psi			
Lane No.	West Edge	Third Point	Third Point	East Edge
1	19P**	23	25	30
	<1800	2250	2600	3500
2	34	24	26	26
	4300	2400	2800	2800
3	30	26	29	24
	3500	2800	3350	2400
4	25	25	24	22
	2600	2600	2400	2100
5	23	28	28	29
	2250	3200	3200	3350
6	27	30	26	24
	2950	3500	2800	2400
7	21	32	28	29
	1900	3900	3200	3350
8	27	23	23	30
	2950	2250	2250	3500
9	28	28	30	22
	3200	3200	3200	2100
10	24	26	26	30
	2400	2800	2800	3500
11	24	26	28	26
	2400	2800	3200	2800
12	28	31	36†	32P
	3200	3750	4750	3900
Mean	25.83	26.83	27.42	27.00
	2766	2966	3055	2950
Rebound Std Deviation	4.06	3.01	3.40	3.44

Note: "P" readings located on oil-based traffic paint.
* Strengths obtained from correlation with rebound numbers.
** Rough.
† Smooth.

Table 4

Stockpile Gradations*

Sieve Size	Percent Passing					
	5/8- to 3/8-in. Range 12.4 Percent of Sample	5/8- to 0-in. Range 74.0 Percent of Sample	Manufactured Sand 6.0 Percent of Sample	Natural Sand 3.0 Percent of Sample	Mineral Filler 3.0 Percent of Sample	Hydrated Lime 1.6 Percent of Sample
5/8-in.	100.0	100.0				
1/2-in.	86.5	96.0				
3/8-in.	12.0	74.5				
No. 4	0.7	23.5	100.0	100.0		
No. 8	0.4	6.0	62.0	95.9	100.0	100.0
No. 200	0.1	0.2	1.2	0.1	80.4	85.8

* Data provided by MRD.

Table 5

Blended Stockpile Gradations*

Sieve Size	Percent Passing			
	5/8- to 3/8-in. Range 12.8 Percent of Sample	5/8- to 0-in. Range 73.3 Percent of Sample	Blended Sand 9.3 Percent of Sample	Blended Sand 4.6 Percent of Sample
5/8-in.	100.0	100.0		
1/2-in.	53.5	97.6		
3/8-in.	5.6	75.5	100.0	
No. 4	0.7	24.8	97.3	
No. 8	0.3	7.6	87.9	100.0
No. 200	0.1	0.3	2.4	63.8

* Data provided by MRD.

Table 6

Job Mix*

Sieve Size	PFC Gradation - Percent Passing: Specification Limits	Job-Mix Formula	Job-Mix Tolerance
5/8-in.	100	100.0	100
1/2-in.	85-95	92.0	89-95
3/8-in.	70-85	73.0	70-76
No. 4	25-40	31.0	28-34
No. 8	15-23**	16.0**	14-18
No. 200	3-5	4.0	3-5
Binder Content, percent	--	6.0	5.8-6.2
Mixing Temperature, °F	--	285.0	±15

* Data provided by MRD.

** Subsequent research by WES indicated that the percent passing the No. 8 sieve should be below 20 percent and this recommendation was used in adopting the job-mix formula.

Table 7

Gradations of Porous Friction Course*
Scott Air Force Base, May 1976

	Percent Passing						Asphaltic	
Paving Lane	5/8 in.	1/2 in.	3/8 in.	No. 4	No. 8	No. 200	Concrete Percent	Mix Temp.
No. 2								
Hot-bins	100	96.0	74.6	33.6	19.5	5.0	--	
Extraction	100	95.6	70.3	35.0	19.6	3.3	6.2	305
No. 3								
Hot-bins	100	95.2	65.8	33.0	19.6	4.8	--	
Extraction	100	93.8	63.7	29.7	15.8	2.7	6.3	300
No. 4								
Hot-bins	100	96.6	65.7	31.8	18.5	4.6	--	
Extraction	100	97.1	60.0	33.3	17.2	3.5	6.3	300
No. 5								
Hot-bins	100	95.8	68.3	36.1	20.8	4.8	--	
Extraction	100	95.8	68.7	30.4	15.4	3.5	6.2	300
No. 6								
Hot-bins	100	94.6	65.4	34.6	19.9	5.0	--	
Extraction	100	97.3	66.7	35.6	17.7	3.4	6.4	310
No. 7								
Hot-bins	100	96.6	68.6	26.3	18.8	4.8	--	
Extraction	100	95.5	66.3	33.2	10.6	3.3	6.2	310
No. 8								
Hot-bins	100	96.2	67.9	34.4	17.0	4.5	--	
Extraction	100	94.6	72.4	34.4	17.1	3.3	6.2	300
No. 9								
Hot-bins	100	95.5	75.9	38.0	17.3	4.7	--	
Extraction	100	94.9	71.1	37.9	17.8	3.6	6.3	305
No. 10								
Hot-bins	100	96.4	71.8	36.2	17.3	4.6	--	
Extraction	100	96.8	73.5	33.8	16.5	3.3	6.3	300
No. 11								
Hot-bins	100	94.8	66.3	32.0	15.9	4.7	--	
Extraction	100	97.0	70.5	31.7	15.4	3.4	6.5	300
No. 12								
Hot-bins	100	96.1	63.3	35.7	18.5	4.8	--	
Extraction	100	95.5	62.3	31.1	15.8	2.9	6.3	300
No. 13 (Not available at time of writing)								
Hot-bins								
Extraction								

* From Department of the Army, Missouri River Division, Corps of Engineers Division Laboratory, Omaha, Nebraska 68102.

Table 8

EXTRACTION TESTS OF POROUS FRICTION COURSE*
Scott Air Force Base, Runway Extension

MRD Lab	Runway Station	Distance from ℄	Sieve Analysis, Cumulative Percent Passing: 5/8 in.	1/2 in.	3/8 in.	No. 4	No. 8	No. 200	Bitumen Content Percent by Weight of Aggregate
A	12+00	65 ft Lt	100	97	75	37	18	5.1	6.2
B	20+00	41 ft Rt	100	98	73	30	15	4.3	7.1
C	20+00	65 ft Rt	100	96	71	30	14	3.1	5.7
D	23+00	29 ft Lt	100	98	71	31	16	4.5	6.7
E	30+00	53 ft Rt	100	97	76	36	19	5.1	6.2
F	31+00	65 ft Lt	100	98	76	35	18	4.8	6.3
G	32+00	65 ft Rt	100	99	76	34	16	4.3	6.3
H	48+00	65 ft Lt	100	99	77	36	16	3.3	5.7
I	50+00	53 ft Lt	100	96	65	32	16	4.2	6.3
J	58+50	41 ft Rt	100	96	63	30	12	1.9	5.8
Specification Limits			100	89-95	71-77	33-39	12-20	3-5	6.20-6.60

* From Department of the Army, Missouri River Division, Corps of Engineers, Division Laboratory, Omaha, Nebraska.

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In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Parker, Frazier
Observations of portland cement concrete and porous friction course pavement construction / by Frazier Parker, Jr., Robert C. Gunkel, Thomas D. White. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1977.
71, [8] p. : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; S-77-26)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C.
References: p. 71.

1. Bituminous concretes. 2. Concretes. 3. Pavements. 4. Porous media. 5. Rigid pavement construction. 6. Skid resistance. 7. Surface friction. I. Gunkel, Robert C., joint author. II. White, Thomas D., joint author. III. United States. Army. Corps of Engineers. IV. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; S-77-26.
TA7.W34m no.S-77-26